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1891–92.

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ERRATA.

Page 133, twenty-eighth line, for Mr. Houdey, read Mr. Hoadley.

NEW ENGLAND WATER WORKS ASSOCIATION.

ORGANIZED 1882.

Vol. VI. March, 1892. No. 3.

This Association, as a Body, is not responsible for statements or opinions of any of its members.

QUARTERLY MEETING.

YOUNG'S HOTEL, BOSTON, MASS., DECEMBER 9TH, 1881.

The following members and guests were present:

MEMBERS.

Solon M. Allis, Supt., Malden, Mass.; George E. Batchelder, Registrar, Worcester, Mass.; Joseph E. Beals, Supt., Middleboro, Mass.; George A. P. Bucknam, Supt., Norwood, Mass.; George F. Chace, Supt., Taunton, Mass.; R. C. P. Coggeshall, Supt., New Bedford, Mass.; H. W. Conant, Supt., Gardner, Mass.; Byron I. Cook, Supt., Woonsocket, R. I.; F. H. Crandall, Supt., Burlington, Vt.; Lucas Cushing, Asst. Supt., Boston, Mass.; F. W. Dean, Mechanical Engineer, Boston, Mass.; J. H. Decker, New York, N. Y.; Prof. T. M. Drown, Boston, Mass.; Horace L. Eaton, City Engineer, Somerville, Mass.; George E. Evans, Civil Engineer, Lowell, Mass.; Frank L. Fuller, Civil Engineer, Boston, Mass.; Albert S. Glover, 113 Devonshire street, Boston, Mass.; W. J. Goldthwait, Marblehead, Mass.; E. P. Gardner, Supt., Norwich, Conn.; J. A. Gould, Jr., Asst. Engineer, Boston, Mass.; S. P. Griffin, Supt., Lowell, Mass.; Frank E. Hall, Supt., Quincy, Mass.; John C. Haskell, Supt., Lynn, Mass.; Horace G. Holden, Supt., Nashua, N. H.; Willard Kent, Civil Engineer, Woonsocket, R. I.; Patrick Kiernan, Supt., Fall River, Mass.; Wilbur F. Learned, Asst. Engineer, Boston Water Works, Watertown, Mass.; Eugene P. Le Baron, Chairman Water Board, Middleboro, Mass.; Thomas C. Lovell, Supt., Fitchburg, Mass.; Charles W. Morse, Haverhill, Mass.; William McNally, Registrar, Marlboro, Mass.; Hiram Nevons, Supt., Cambridge, Mass.; Edward C. Nichols, Water Commissioner, Reading, Mass.; Albert F. Noyes, City Engineer, West Newton, Mass.; Walter H. Richards, Supt., New London,

Conn.; George J. Ries, Supt., Weymouth Centre, Mass.; A. H. Salisbury, Supt., Lawrence, Mass.; Charles W. S. Seymour, Supt., Hingham, Mass., William B. Sherman, Mechanical Engineer, Providence, R. I.; Geo. A. Stacy, Supt., Marlboro, Mass.; Frederick P. Stearns, Chief Engineer State Board of Health, Boston, Mass.; Charles K. Walker, Supt., Manchester, N. H.; John C. Whitney, Water Registrar, West Newton, Mass.; Horace B. Winship, Civil Engineer, Norwich, Conn.; George E. Winslow, Supt., Waltham, Mass.; James M. Betton, W. C. Brown, of H. R. Worthington, New York City; C. H. Eglee, Contractor, Flushing, N. Y.; J. H. Tilden, Hersey Meter Co., South Boston, Mass.; Robert Thomas, National Meter Co., New York City; H. L. Bond, Perrin, Seamans & Co., Boston, Mass.; Wilmer Reed, The McNeal Pipe and Foundry Co., Burlington, N. J.; H. P. Hutchinson, Standard Thermometer Co., Peabody, Mass.; E. L. Abbott, Thomson Meter Co., New York City; A. A. Blossom, Whittier Machine Co., Boston, Mass.; Jesse Garrett, R. D. Wood & Co., Philadelphia, Pa.; H. A. Gorham, The George Woodman Co., Boston, Mass.

GUESTS.

Ezra Stevens, Malden, Mass.; J. A. Bryant, Burlington, Vt.; H. W. Haskins, Weymouth Centre, Mass.

After lunch the President called the meeting to order.

Applications for membership from the following parties, having been approved by the Executive Committee, they were elected:

RESIDENT ACTIVE MEMBERS.

Edwin P. Gardner, Supt., Norwich, Conn.; James A. Huntington, Registrar, Haverhill, Mass.; Frederick W. Sawyer, Registrar, Milford, N. H.; Elbert Wheeler, Treasurer (several water companies), Nashua, N. H.

NON-RESIDENT ACTIVE MEMBERS.

William Pitman, General Manager, Jerseyville, Ill.

ASSOCIATE MEMBERS.

Francis M. Weld, M. D., Jewell Water Filter, Jamaica Plain, Mass.

The President introduced Mr. J. H. Decker, Secretary of the American Water Works Association, who made a few remarks.

Mr. Nevons referred to the continued illness of Mr. William M. Hawes, and Messrs. Nevons and Hall were appointed a committee to convey the best wishes of the Association to him.

The President introduced Mr. Frederic P. Stearns, Chief Engineer of the Massachusetts State Board of Health, who read a paper entitled "The Selection of Sources of Water Supply," which was discussed by Messrs. Fuller, Noyes, Prof. Drown, Allis, Whitney, Richards, Chase and Tilden. Adjourned.

ADJOURNED MEETING.

YOUNG'S HOTEL, BOSTON, MASS., JANUARY 13TH, 1892.

The following members and guests were present:

MEMBERS.

Charles H. Baldwin, Boston, Mass.; George E. Batchelder, Registrar, Worcester, Mass.; William R. Billings, Taunton, Mass.; George A. P. Bucknam, Supt., Norwood, Mass.; George F. Chace, Supt., Taunton, Mass.; Byron I. Cook, Supt., Woonsocket, R. I.; Horace L. Eaton, City Engineer, Somerville, Mass.; Desmond Fitz Gerald, Supt. Western Division, Boston Water Works, Brookline, Mass.; F. F. Forbes, Supt., Brookline, Mass.; Z. R. Forbes, Asst. Supt., Brookline, Mass.; Frank L. Fuller, Civil Engineer, Boston, Mass.; Albert S. Glover, Boston, Mass.; J. A. Gould, Jr., Engineer, Boston, Mass.; S. P. Griffin, Supt., Lowell, Mass.; George W. Harrington, Supt., Wakefield, Mass.; John L. Harrington, Cambridge, Mass.; John C. Haskill, Supt., Lynn, Mass.; H. G. Holden, Supt., Nashua, N. H.; Horatio W. Hyde, Supt., Newtonville, Mass.; Patrick Kiernan, Supt., Fall River, Mass.; George A. Kimball, Civil Engineer, Boston, Mass.; W. E. McClintock, Civil Engineer, Boston, Mass.; Edward C. Nichols, Commissioner, Reading, Mass.; Edward H. Phipps, Supt., New Haven, Conn.; Dwight Porter, Inst. of Technology, Boston, Mass.; Walter H. Richards, Supt., New London, Conn.; George J. Ries, Supt., Weymouth Centre, Mass.; A. H. Salisbury, Supt., Lawrence, Mass.; Reuben Shirreffs, Richmond, Va.; George A. Stacy, Supt., Marlboro, Mass.; Frederick P. Stearns, Engineer, Boston, Mass.; Lucien A. Taylor, Civil Engineer, Boston, Mass.; M. M. Tidd, Hydraulic Engineer, Boston, Mass.; D. N. Tower, Supt., Cohasset, Mass.; Charles K. Walker, Supt., Manchester, N. H.; Joseph Watters, Commissioner, Fall River, Mass.; John C. Whitney, Registrar, West Newton, Mass.; George E. Winslow, Supt., Waltham, Mass.

ASSOCIATE MEMBERS.

A. H. Broderick, Chadwick Lead Works, Boston, Mass.; E. L. Ross, Chapman Valve M'fg. Co., Indian Orchard, Mass.; F. H. Hayes, Dean Steam Pump Co., Holyoke, Mass.; J. A. Tilden, Hersey M'fg. Co., Boston, Mass.; C. E. Roberts, Boston, Mass.; E. L. Abbott, Thompson Meter Co., New York City; H. A. Gorham, The George Woodman, Co., Boston, Mass.; J. M. Betton, H. R. Worthington, New York City.

GUESTS.

Prof. C. F. Allen, Boston, Mass.; William H. Allen, Boston, Mass.; H. E. Abbott, Hanover, N. H.; A. A. Blossom, Wakefield, Mass.; M. M. Boardman, Worcester, Mass.; George K. Crandall, New London, Conn.; A. W. Custance, Weymouth Centre, Mass.; Joseph R. Hews, Roxbury, Mass.; J. H. Howland, New Bedford, Mass.; J. J. McKee, Paterson, N. J.; Thomas H. Wilson, Paterson, N. J.; Burnham Reith, Peabody, Mass.; George S. Rice, Boston, Mass.; J. E. Self, Boston, Mass.

Mr. Richards, Secretary *pro tem*, presented applications for membership from the following named gentlemen :

RESIDENT ACTIVE MEMBERS.

George A. Sanders, President Water Works Co., Hudson, N. H.; John F. Springfield, Civil Engineer, Rochester, N. H.; Frederick J. Winslow, Engineering Department, Water Works, 49 City Hall, Boston, Mass.

ASSOCIATE MEMBERS.

George K. Paul & Co., Pipe and Fittings, 98 Milk street, Boston, Mass.

The applications having been approved by the Executive Committee, the applicants were elected.

The Secretary read a letter from William M. Hawes, expressing his gratitude for the interest taken in him by the Association during his long illness.

The President introduced Mr. Reuben Shirreffs, second assistant Engineer of the East Jersey Water Company, who read a paper entitled "The New Water Supply of Newark, N. J., with special reference to the Riveted Steel Pipe Conduit." The paper was illustrated by lantern views.

After discussion by the President and Mr. Fitz Gerald, the Association, by a rising vote, expressed its thanks to Mr. Shirreffs for his interesting paper. Adjourned.

THE SELECTION OF SOURCES OF WATER SUPPLY.*

BY

FREDERIC P. STEARNS, Chief Engineer Massachusetts State Board of Health.

As a part of my official duties, I have occasion to investigate many proposed water supplies each year with reference to the probable quantity and quality of water to be obtained. With so much of this work to be done it has become important to reduce the labor of computation as much as possible, and with this in view, the existing data regarding the yield of water sheds has been put in more convenient form for use than heretofore. I have also had occasion to gather some statistics as to the yield of ground water sources. These features, together with a somewhat extended general consideration of the quantity and quality of surface and ground waters make up the paper which I present to you this afternoon.

In preparing this paper, the examination of existing water supplies in

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* The paper already published in the Journal of the Association of Engineering Societies is reproduced here, instead of the shorter one read at the meeting of the N. E. W. W. Ass'n.

Massachusetts,* which has been carried on for more than four years by the State Board of Health—in part under my immediate direction—has been of great assistance.

In selecting a source of water supply it is essential that all water should be rejected which is seriously polluted with domestic sewage. There are other waters not so polluted, as, for instance, those having a disagreeable taste and odor or drawn directly from swamps, which are manifestly unfit for drinking. A water may also be rejected by reason of its extreme hardness which makes it unsuitable for washing purposes and for use in boilers. Among the waters which may be used there is a large difference in quality, and this in connection with the quantity and cost should receive careful consideration in making the selection.

The prominent characteristic of ground water is freedom from color and organic matter (including microscopic organisms), while surface waters are frequently colored with vegetable matter derived from swamps, and almost always contain a greater or less number of microscopic organisms. These organisms, when abundant, frequently impart to the water a disagreeable taste and odor.

With regard to the question of quantity, sufficient surface water can be obtained for the largest cities, and the amount which can be obtained from a given water-shed can be estimated in advance with a large degree of accuracy. Ground water supplies, on the other hand, are much more limited in quantity, and the amount to be obtained from any given place cannot be as accurately predicted.

As a whole we may say that when unpolluted ground water can be obtained in sufficient quantity from regions where the water does not dissolve much mineral matter and in this way become hard, it is very much to be preferred to surface water for the supply of a city or town.

In this paper water taken from wells and filter-galleries built beside streams and ponds, and deriving their water in part, from these surface waters, by filtration, will be considered as ground waters.

QUANTITY OF SURFACE WATER.

All sources from which water is obtained depend for their supply upon the rain which falls upon the area from which the water can flow over the surface or underground to the point whence it is taken for use. In a great majority of cases this area coincides with the superficial water-shed of the stream or pond utilized. We have, therefore, as very important factors affecting the quantity of water, the amount of the annual rainfall and the area of the water-shed.

The whole of the rain which falls upon a water-shed does not flow off into the streams, because much is lost by evaporation from the surface of the ground. The amount of this loss has been determined practically by com-

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*This paper, being based mainly upon observations in Massachusetts, has been written with especial reference to this State; in many respects, however, the statements made will have a wider application,

paring the quantity of water falling upon a given water-shed (as deduced from the depth of rainfall and the area of the water-shed) with the amount of water flowing off in the streams. Very valuable records of this character have been kept by the city of Boston for many years at Cochituate Lake, Sudbury River and Mystic Lake, and the results have been published in the annual reports of the Boston Water Board. From these we learn that the average percentage of rainfall collected from these three water-sheds is as follows :

	Average. Rainfall. — Inches.	Average. Rainfall. Collected. — Inches.	Per Cent. Collected.
Lake Cochituate (28 years' observations), ...	47.82	20.55	42.97
Sudbury River (16 years' observations), ...	45.80	22.67	49.50
Mystic Lake (13 years' observations), ...	44.11	20.22	45.84

In attempting to determine the quantity of water which can be made available for use from any given source, the above figures, representing the average results of many years' observation, have only a limited value, because there is a marked variation in the amount of rainfall in different years and a still greater difference in the amount of rainfall collected, the rule being that the percentage collected decreases with the amount of the annual rainfall ; moreover, there is a vast difference in the amount of rainfall collected at different seasons of the year. In view of these differences it is obviously necessary to take into account the rainfall collected during dry periods of much less than a year's duration. This can be done by means of the records of the Boston Water Works above referred to. Of these the Sudbury River records are the most accurate and the most generally applicable to conditions existing at other places, and, on account of their value as a basis for water supply estimates, they are reproduced from the reports of the Boston Water Board in the following table. The rainfall collected is also shown graphically upon the diagram opposite page 107.

The most prominent feature of the table and diagram is the immense difference in the amount of water collected in the spring and in the summer ; but the difference between the flow of different years is also very great. The dryest years were 1880 and 1883, in each of which there was a severe drought during the last seven months, and even during the spring of each of these years the amount collected was much less than in other years. The summer of 1889 was in marked contrast with all of the others, the flow being unprecedentedly high.

As has already been indicated it is necessary in estimating the capacity of sources of water supply to take into account the dryest periods which have occurred, and which consequently may recur ; and for this reason it is the

Rainfall Received and Collected on the Sudbury River Water-shed.

Month.	1875.			1876.			1877.			1878.			1879.			1880.		
	Rainfall.	Rainfall Collected.	Per Cent. Collected.	Rainfall.	Rainfall Collected.	Per Cent. Collected.	Rainfall.	Rainfall Collected.	Per Cent. Collected.	Rainfall.	Rainfall Collected.	Per Cent. Collected.	Rainfall.	Rainfall Collected.	Per Cent. Collected.	Rainfall.	Rainfall Collected.	Per Cent. Collected.
	Inches	*Inches*		*Inches*	*Inches*		*Inches*	*Inches*		*Inches*	*Inches*		*Inches*	*Inches*		*Inches*	*Inches*	
January,	2.42	0.184	7.6	1.83	1.147	62.7	3.216	1.174	36.5	5.632	3.228	57.3	2.478	1.249	50.4	3.566	2.000	56.02
February,	3.15	2.411	76.5	4.21	2.282	54.2	0.739	1.529	206.9	5.973	3.972	66.5	3.562	2.756	77.4	3.980	2.982	74.92
March,	3.74	2.862	76.5	7.43	7.911	106.5	8.357	8.586	102.7	4.689	6.256	133.4	5.140	4.156	80.9	3.315	2.451	73.93
April,	3.23	5.263	162.9	4.197	5.683	135.4	3.435	4.132	120.3	5.790	2.807	48.5	4.716	5.379	114.1	3.105	2.017	64.97
May,	3.56	2.119	59.5	2.763	2.031	73.5	3.702	2.482	67.0	0.956	2.487	260.2	1.579	1.987	125.8	1.836	0.917	49.95
June,	6.24	1.501	24.0	2.040	0.383	18.8	2.425	1.031	42.5	3.884	0.873	22.5	3.789	0.713	18.8	2.138	0.303	14.16
July,	3.57	0.573	16.0	9.134	0.326	3.6	2.951	0.360	12.2	2.971	0.229	7.7	3.933	0.281	7.1	6.273	0.315	5.02
August,	5.53	0.706	12.8	1.720	0.723	42.0	3.682	0.216	5.9	6.937	0.848	12.2	6.509	0.705	10.8	4.008	0.212	5.29
September,	3.43	0.358	10.4	4.614	0.318	6.9	0.323	0.103	31.9	1.291	0.277	21.5	1.878	0.243	12.9	1.603	0.138	8.64
October,	4.85	1.152	23.8	2.241	0.417	18.6	8.515	1.127	13.2	6.417	0.921	14.3	0.809	0.126	15.6	3.740	0.181	4.85
November,	4.83	2.248	46.5	5.764	1.878	32.6	5.803	2.447	42.2	7.024	2.922	41.6	2.682	0.355	13.2	1.785	0.354	19.85
December,	0.94	1.041	110.7	3.620	0.809	22.3	0.870	2.300	264.4	6.367	5.667	89.0	4.344	0.825	19.0	2.828	0.312	11.05
Totals and Averages,	45.49	20.418	44.9	49.563	23.908	48.2	44.018	25.487	57.9	57.931	30.487	52.6	41.419	18.775	45.3	38.177	12.182	31.91

Rainfall Received and Collected on the Sudbury River Water-shed—CONTINUED.

MONTH.	1881.			1882.			1883.			1884.			1885.			1886.		
	Rainfall.	Rainfall Collected.	Per Cent. Collected.	Rainfall.	Rainfall Collected.	Per Cent. Collected.	Rainfall.	Rainfall Collected.	Per Cent. Collected.	Rainfall.	Rainfall Collected.	Per Cent. Collected.	Rainfall.	Rainfall Collected.	Per Cent. Collected.	Rainfall.	Rainfall Collected.	Per Cent. Collected.
	Inches	*Inches*		*Inches*	*Inches*		*Inches*	*Inches*		*Inches*	*Inches*		*Inches*	*Inches*		*Inches*	*Inches*	
January,	5.558	0.740	13.31	5.951	2.213	37.19	2.81	0.597	21.25	5.085	1.775	34.91	4.71	2.203	46.76	6.365	2.606	40.94
February,	4.646	2.491	53.62	4.546	3.872	85.18	3.865	1.664	43.05	6.545	4.742	72.45	3.865	2.182	56.44	6.28	7.734	123.16
March,	5.730	7.142	124.64	2.649	5.064	191.16	1.78	2.873	161.42	4.72	6.752	143.06	1.07	2.805	262.14	3.61	3.672	101.72
April,	2.000	2.669	133.44	1.824	1.497	82.09	1.845	2 330	126.27	4.405	4.925	111 82	3.605	3.133	86.91	2.225	3.361	151.06
May,	3.511	1.721	49.03	5.066	2.304	45.48	4.185	1.673	39.96	3.47	1.838	52.97	3.485	2.383	68.38	2.995	1.285	42.90
June,	5.395	2.309	42.80	1.664	0.913	54.87	2.40	0.518	21.58	3.445	0.719	20.86	2.865	0.735	25.66	1.465	0.350	23.93
July,	2.350	0.493	20.98	1.769	0.154	8.70	2.68	0.206	7.68	3.665	0.399	10.89	1.425	0.111	7.77	3.265	0.206	6.32
August,	1.358	0.264	19.45	1.667	0.099	5.91	0.735	0.140	19.06	4.65	0.458	9.85	7.185	0.429	5.97	4.10	0.168	4.09
September,	2.617	0.340	13.01	8.741	0.529	6.05	1.52	0.157	10.36	0.855	0.076	8.87	1.425	0.209	14.66	2.905	0.203	6.98
October,	2.955	0.331	11.20	2.074	0.534	25.74	5.60	0.331	5.92	2.48	0.148	5.98	5.095	0.599	11.75	3.235	0.260	8.04
November,	4.091	0.682	16.66	1.147	0.362	31.51	1 81	0.354	19.52	2.645	0.302	11 44	6.095	2.033	33.35	4.645	1.161	25.01
December,	3.958	1.383	34.93	2.296	0.561	24.45	3.55	0.345	9.72	5.17	1.650	31.91	2.72	2.094	76.99	4.975	1.819	36.56
TOTALS AND AVERAGES,	44.169	20.565	46.56	39.394	18.102	45.95	32.78	11.188	34.13	47.135	23.784	50.46	43.545	18.916	43.44	46.065	22.825	49.55

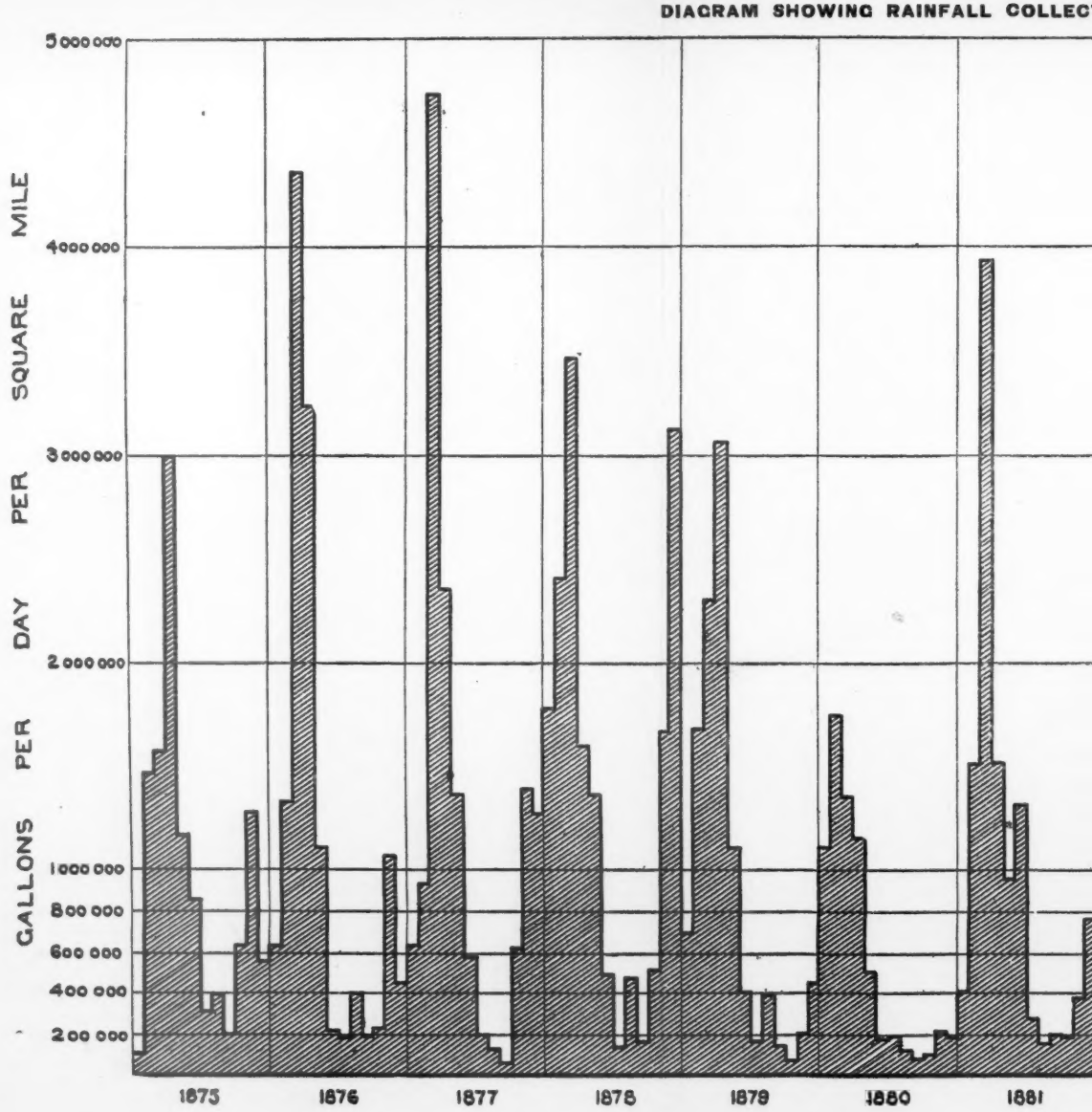
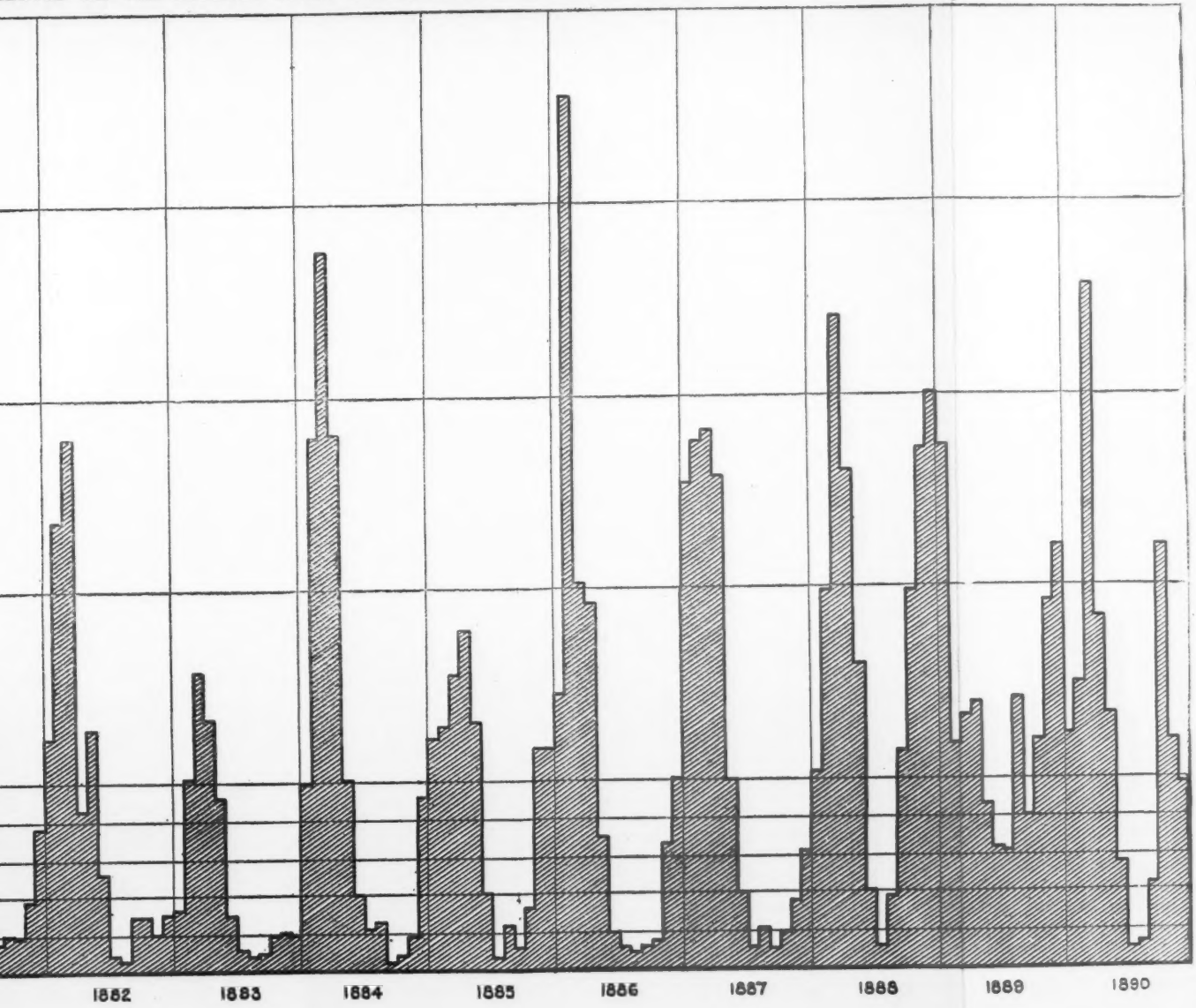


DIAGRAM SHOWING RAINFALL COLLEC
GALLONS PER DAY PER SQUARE MILE
5 000 000
4 000 000
3 000 000
2 000 000
1 000 000
800 000
600 000
400 000
200 000
1875
1876
1877
1878
1879
1880
1881

LECTED ON THE SUDBURY RIVER WATERSHED FROM 1875 TO 1890.



Rainfall Received and Collected on the Sudbury River Water-shed.—CONCLUDED.

MONTH.	1887.			1888.			1889.			1890.			Mean for 16 Years. 1875–1890.		
	Rainfall.	Rainfall Collected.	Per Cent. Collected.	Rainfall.	Rainfall Collected.	Per Cent. Collected.	Rainfall.	Rainfall Collected.	Per Cent. Collected.	Rainfall.	Rainfall Collected.	Per Cent. Collected.	Rainfall.	Rainfall Collected.	Per Cent. Collected.
	Inches	*Inches*		*Inches*	*Inches*		*Inches*	*Inches*		*Inches*	*Inches*		*Inches*	*Inches*	
January,	5.20	4.619	88.82	4.15	1.878	45.26	5.37	4.963	92.42	2.53	2.237	88.43	4 179	2.051	49.08
February,	4.78	4.558	95.35	3.685	3.255	88.32	1.655	1.926	116.39	3.505	2.464	70.29	4.062	3.176	78.19
March,	4.90	5.116	104.40	6.02	5.775	95.93	2.365	2.388	100.95	7.735	6.498	84.01	4.578	5.019	109 63
April,	4.265	4.522	106.03	2.425	4.566	188.30	3.41	2.434	71.37	2.645	3.236	122.35	3.329	3.622	109 10
May,	1.165	1.799	154.46	4.825	2.912	60.35	2.945	1.569	53.27	5.21	2.437	46.78	3.203	1.996	62.32
June,	2.65	0.714	26.93	2.535	0.728	28.70	2.80	1.128	40.27	2.03	0.980	48.27	2.985	0.869	29.11
July,	3.76	0.204	5.45	1.405	0.209	14.90	8.94	1.130	12.64	2.46	0.192	7.78	3.784	0.337	8.91
August,	5.28	0.382	7.24	6.225	0.677	10.87	4.175	2.554	61.18	3.865	0.235	6.08	4.227	0.552	13.06
September,	1.32	0.191	14.52	8.585	1.994	23.22	4.605	1.422	30.87	6.00	0.790	13.16	3.232	0.459	14.20
October,	2.835	0.339	11.96	4.99	3.566	71.45	4.255	2.194	51.57	10.51	4.053	38.56	4.413	1.017	23.05
November,	2.67	0.636	23.83	7.225	4.761	65.90	6.29	3.351	53.27	1.20	2.097	174.72	4.107	1.621	39.47
December,	3.88	1.147	29.58	5.395	5.428	100.60	3.14	3.997	127 30	5.31	1.779	33.49	3.710	1.947	52.48
TOTALS AND AVERAGES,	42.705	24.227	56.73	57.465	35.749	62.21	49.95	29.056	58.17	53 000	26.998	50.94	45 800	22.667	49.49

minimums recorded in the foregoing table which have the most value. These for periods varying in duration from one month to sixteen years have been carefully selected from the table, and are presented in more convenient form in the one which follows:

*Table showing the Average Daily Flow from the Sudbury River Water-shed for Different Periods, varying from One Month to Sixteen years, selecting in each case the Dryest Period of the Given Duration.**

Length of Period.	Dates.	Average Daily Flow of Water-shed.		
		Gallons Per Day Per Square Mile.	Gallons Per Day Per Acre.	Cubic Feet Per Second Per Square Mile.
1 month	September, 1884	44,000	69	.068
2 months	Sept. 1, 1884, to Oct. 31, 1884	64,000	100	.099
3 months	July 1, 1883, to Sept. 30, 1883	95,000	148	.147
4 months	July 1, 1883, to Oct. 31, 1883	118,000	184	.183
5 months	June 1, 1880, to Oct. 31, 1880	131,000	205	.203
6 months	June 1, 1880, to Nov. 30, 1880	143,000	223	.221
7 months	June 1, 1880, to Dec. 31, 1880	147,000	230	.227
8 months	June 1, 1880, to Jan. 31, 1881	181,000	283	.280
9 months	May 1, 1880, to Jan. 31, 1881	219,000	342	.339
10 months	April 1, 1880, to Jan. 31, 1881	312,000	487	.483
11 months	Mar. 1, 1880, to Jan. 31. 1881	409,000	639	.633
1 year	Mar. 1, 1880, to Feb. 28, 1881	497,000	777	.769
2 years	Feb. 1, 1882, to Jan. 31, 1884	687,000	1,073	1.063
3 years	Mar. 1, 1880, to Feb. 28, 1883	764,000	1,194	1.182
4 years	Feb. 1, 1880, to Jan. 31, 1884	735,000	1,148	1.137
5 years	Jan. 1, 1879, to Dec. 31, 1883	769,000	1,202	1.190
6 years	Oct. 1, 1879, to Sept. 30, 1885	803,000	1,255	1.242
7 years	Jan. 1, 1879, to Dec. 31, 1885	839,000	1,311	1.298
8 years	Jan. 1, 1879, to Dec. 31, 1886	870,000	1,359	1.346
9 years	Jan. 1, 1879, to Dec. 31, 1887	902,000	1,409	1.396
10 years	April 1, 1878, to Mar. 31, 1888	944,000	1,475	1.461
11 years	Jan. 1, 1875, to Dec. 31, 1885	968,000	1,512	1.498
12 years	Jan. 1, 1875, to Dec. 31, 1886	978,000	1,528	1.513
13 years	Jan. 1, 1875, to Dec. 31, 1887	991,000	1,548	1.533
14 years	Jan. 1, 1875, to Dec. 31, 1888	1,042,000	1,628	1.612
15 years	Jan. 1, 1875, to Dec. 31, 1889	1,065,000	1,664	1.648
16 years	Jan. 1, 1875, to Dec. 31, 1890	1,079,000	1,686	1.670

With such a vast difference in the average daily flow during the dryest month and the dryest year, and also in the flow during the dryest year and a long series of years, it is obvious that the quantity of water which can be made available from a given water-shed depends very much upon the amount

* Since this table was prepared a corresponding one has been made by Mr. A. Fteley, Chief Engineer of the New York Aqueduct Commission, based upon the flow of the Croton water-shed for 17 years, from 1870 to 1886 inclusive, which, with his permission, is given here.

Table showing the Average Daily Flow from Croton River for Different Periods, varying from One Month to Seventeen Years, selecting in each case the Dryest Period of the Given Duration.

Length of Period.	Dates.	Average Daily Flow of Water-shed.		
		Gallons Per Day Per Square Mile.	Gallons Per Day Per Acre.	Cubic Feet Per Second Per Square Mile.
1 month	September, 1877	187,200	292.5	0.290
2 months	Sept. and Oct., 1876	204,900	320.2	0.317
3 months	Aug. 1 to Oct. 31, 1876	226,300	353.7	0.350
4 months	July 1 to Oct. 31, 1870	242,100	378.4	0 375
5 months	July 1 to Nov. 30, 1870	262,500	410.3	0.406
6 months	July 1 to Dec. 31, 1870	276,200	431.6	0.427
7 months	July 1, 1870, to Jan. 31, 1871	282,200	441.1	0.437
8 months	June 1, 1880, to Jan. 31, 1881	302,400	472.6	0.466
9 months	May 1, 1880, to Jan. 31, 1881	327,200	511.4	0.506
10 months	April 1, 1880, to Jan. 31, 1881	410,800	642.0	0.636
11 months	Mar. 1, 1880, to Jan. 31, 1881	520,200	813.0	0.805
1 year	Feb. 1, 1880, to Jan. 31, 1881	619 500	968.0	0.959
2 years	July 1, 1870, to June 31, 1872	846,100	1,322.0	1.309
3 years	July 1, 1879, to April 30, 1882	890,300	1,391.2	1.377
4 years	Feb. 1, 1880, to Jan. 31, 1884	886,200	1,384.8	1.371
5 years	Jan. 1, 1879, to Dec. 31, 1883	926,300	1,447.5	1.433
6 years	Nov. 1, 1879, to Oct. 31, 1885	930,100	1,453.3	1.439
7 years	Jan. 1, 1880, to Dec. 31, 1886	955,100	1,492.5	1.478
8 years	Jan. 1, 1879, to Dec. 31, 1886	968,200	1,513.0	1.498
9 years	Aug. 1, 1876, to July 31, 1885	996,500	1.557.0	1.542
10 years	May 1, 1876, to April 31, 1886	1,009,400	1,577.3	1.562
11 years	Jan. 1, 1876, to Dec. 31, 1886	1,025,400	1,602.0	1.587
12 years	Nov. 1, 1874, to Oct. 31, 1886	1,046,300	1,635.0	1.619
13 years	Jan. 1, 1874, to Dec. 31, 1886	1,056,400	1,650.7	1.635
14 years	July 1, 1870, to June 31, 1884	1,057,300	1,652.2	1.636
15 years	Jan. 1, 1872, to Dec. 31, 1886	1,060,100	1,656.5	1.643
16 years	July 1, 1870, to June 31, 1886	1,057,000	1,651.7	1.636
17 years	Jan. 1, 1870, to Dec. 31, 1886	1,051,200	1,642.5	1.626

During this period the average rainfall on the Croton water-shed has been 45.98 inches, showing a remarkable correspondence with the average rainfall on the Sudbury water-shed during the sixteen years included in the table, which was 45.80 inches. The average amount collected from the water-shed per square mile during the whole period in the two cases also shows a remarkable agreement, the average daily flow from the Sudbury water-shed being 1,079,000 gallons and from the Croton water-shed 1,051,200. For the dryest year the flow from the Croton water-shed was one-fourth greater than from the Sudbury water-shed, indicating, that there has never been as great drought upon the Croton water-shed as upon the Sudbury. For periods of only one or two months the minimum flow from the Croton water-shed is about four times as much per square mile as from the Sudbury, which may be due in part to the less extreme drought, and in part to the larger area of the water-shed which would tend to maintain a larger flow in the streams through very dry periods. Other causes, such as the influence of ponds and lakes within the water-shed, would also have an influence upon the minimum flow.—F. P. S.]

which can be stored in seasons when water is abundant for use during seasons of drought.

A table will be presented subsequently to show directly the amount of storage required to make available different daily volumes of water per square mile of water-shed; but as this will take into account the effect of a greater or less amount of water surfaces in the water-shed, the relation of the evaporation from water surfaces to the rainfall upon them will be considered first.

The most valuable information upon the subject of evaporation is to be obtained from the paper presented by Mr. Desmond FitzGerald* to the American Society of Civil Engineers. His paper was based chiefly upon observations and experiments made at the Chestnut Hill Reservoir of the Boston Water Works, and contains among other things, a mean evaporation for each month of an ordinary year. By comparing this with the mean rainfall the relation between the two can be established; and, as the evaporation does not vary much from year to year, we can also obtain approximately the relation between the evaporation and rainfall in a dry year, by comparing the average evaporation with the rainfall in a dry year, like 1883.

The results of these comparisons are shown by the following table and diagram:

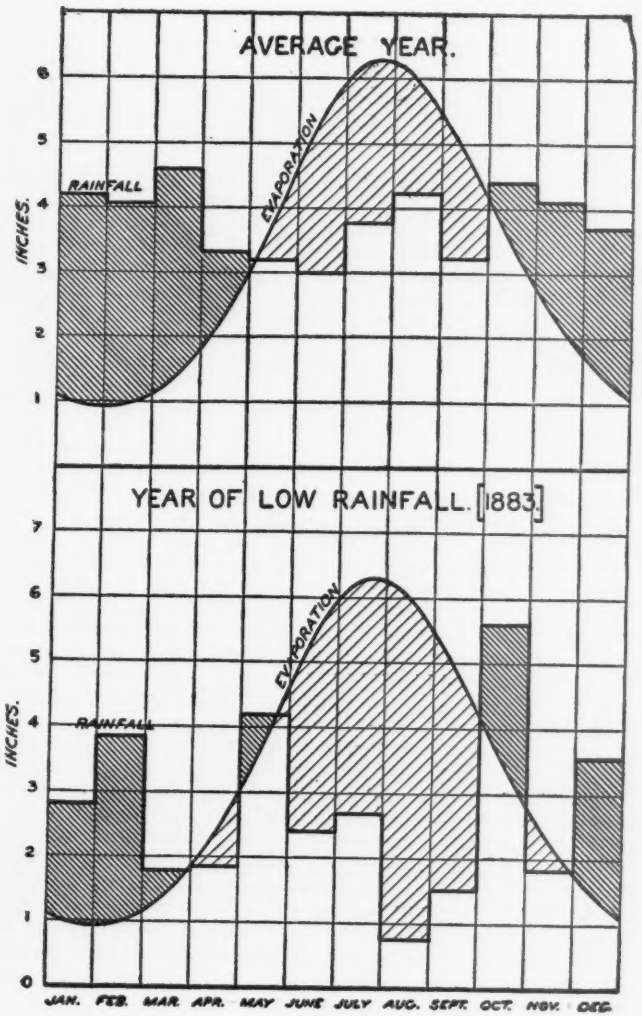
Table showing Relation of Evaporation to Rainfall.

MONTH.	AVERAGE YEAR.			YEAR OF LOW RAINFALL.		
	Rainfall. Inches.	Evaporation. Inches	Excess or Def'ncy of Rainfall. Inches.	Rainfall. Inches.	Evaporation. Inches.	Excess or Def'ncy of Rainfall. Inches.
January	4.18	0.98	+3.20	2.81	0.98	+1.83
February	4.06	1.01	+3.05	3.86	1.01	+2.85
March	4.58	1.45	+3.13	1.78	1 45	+0.33
April	3.32	2.39	+0.93	1.85	2.39	−0.54
May	3.20	3.82	−0.62	4.18	3.82	+0.36
June	2.99	5.34	−2.35	2.40	5.34	−2.94
July	3.78	6.21	−2.43	2.68	6.21	−3.53
August	4.23	5.97	−1.74	0.74	5.97	−5.23
September	3.23	4.86	−1.63	1.52	4.86	−3.34
October	4.41	3.47	+0.94	5.60	3.47	+2.13
November	4.11	2.24	+1.87	1.81	2.24	−0.43
December	3.71	1.38	+2.33	3.55	1.38	+2.17
	45.80	39.12	+6.68	32.78	39.12	−6.34

NOTE. + indicates excess of rainfall; — indicates deficiency.

It will be seen from the facts presented that the monthly rainfall varies much less during the year than the evaporation; also that in an average year the rainfall is 6.68 inches greater than the evaporation. The average year may be divided into two periods, one extending from May to September, inclusive,

*Evaporation, by Desmond FitzGerald, C. E., Transactions of the American Society of Civil Engineers, Vol. XV., 1886, p. 581.


AVERAGE YEAR.
INCHES.
RAINFALL
EVAPORATION
YEAR OF LOW RAINFALL. [1883]
INCHES.
RAINFALL
EVAPORATION
JAN. FEB. MAR. APR. MAY JUNE JULY AUG. SEPT. OCT. NOV. DEC.

in which the evaporation is 8.77 inches greater than the rainfall; and the other extending from October to April, inclusive; in which the rainfall exceeds the evaporation by 15.45 inches.

In the year of low rainfall the evaporation was 6.34 inches greater than the rainfall. During the warmer months, from April to September, inclusive, the excess of evaporation was 15.22 inches, and during the other six months the rainfall was 8.88 inches in excess of the evaporation. These figures indicate that a pond will not lower by evaporation in a dry summer more than about fifteen inches, even if it receives no water from its water-shed.

The following table gives the quantity of water which may be made avaiable per square mile of water-shed (estimating land surface only), with varying amounts of storage and a varying percentage of water surfaces. In preparing the table, the records of the flow of Sudbury River and of the rainfall upon the Sudbury River water-shed from 1875 to 1890, inclusive, as given in the table on pages 105–107, have been used; also the records of evaporation from water surfaces deduced from observations made at Chestnut Hill Reservoir during the years 1876 to 1880 and 1885 to 1887. For other years, when the evaporation was not measured, the average evaporation, as given in the table on page 110 has been used. The flow per square mile is in all cases the smallest recorded after taking into account the evaporation from water surfaces.

Table showing the Amount of Storage required to make available Different Daily Volumes of Water per square Mile of Water-shed (estimating land surfaces only) corrected for the Effect of Evaporation and Rainfall on Varying Percentages of Water Surfaces, not included in estimating the area of the Water-shed.

Daily Volume in Gallons per Square Mile of Land Surface.	Storage required in Gallons per Square Mile of Land Surface to prevent a Deficiency in the Season of Greatest Drought when the Daily Consumption is as indicated in the First Column, with the following Percentages of Water Surfaces.				
	0 Per Cent.	3 Per Cent.	6 Per Cent.	10 Per Cent.	25 Per Cent.
100,000	556,000	3,000,000	8,800,000	—	—
150,000	3,400,000	7,100,000	13,400,000	—	—
200,000	9,400,000	11,700,000	18,000,000	—	—
250,000	19,000,000	22,200,000	25,400,000	—	—
300,000	29,800,000	33,000,000	36,100,000	—	—
400,000	52,000,000	54,400,000	57,500,000	—	—
500,000	76,500,000	77,300,000	80,300,000	—	—
600,000	102,000,000	104,600,000	107,100,000	112,800,000	—
700,000	144,400,000	153,000,000	161,600,000	170,700,000	215,900,000
800,000	202,300,000	210,900,000	219,500,000	228,600,000	273,800 000
900,000	346,200,000	349,200,000	352,200,000	353,900,000	381,600,000
1,000,000	514,600,000	516,700,000	519,700,000	523,600,000	532,200,000

I will call particular attention to this table, because it contains in a convenient form for use, all of the information with regard to minimum quantities which the Sudbury River records as published will furnish, and in addition it takes into account the effect of evaporation from varying percentages of water surfaces.

Having given the area of the water-shed, (land surface only), the area of water surfaces, and the available storage capacity, the yield of a source can be calculated in a few minutes with the aid of the table.

As an illustration of its use, let us assume that it is desired to know the yield of a pond having an area of .15 of a square mile and an available storage capacity of 225,000,000 gallons, which has draining into it 1.5 square miles of land surface. The amount of storage in this case would be equivalent to 150,000,000 gallons per square mile of land surface, and the water surface would equal ten per cent. of the land surface. By looking in the column of the table headed ten per cent. it will be seen that a storage of 150,000,000 gallons per square mile corresponds to a daily volume of between 600,000 and 700,000 gallons per square mile, or more exactly by proportion to 660,000 gallons, equal to 990,000 gallons daily for the whole water-shed. The results obtained by this method will in some cases be practically correct. In other cases it will be necessary to take account of local conditions, prominent among which may be leakage past a dam or filtration through the ground to lower levels; and the application of judgment will often be necessary to determine whether the water-shed under consideration will yield the same, or a greater or less amount per square mile than that of the Sudbury River. To aid in judging the relative yield, it will be well to state the conditions which existed upon the Sudbury River water-shed during the time included in the records.

The area of the water-shed from which the flow was measured was 77.764 square miles until the end of 1878, then 78.238 square miles until the end of 1880, and after that time 75.199 square miles. These areas include all water surfaces. From the beginning of the observations until the end of 1878, the water surfaces consisted of Farm Pond, Whitehall Pond, (which was flowed in winter and drawn down in summer), several mill ponds, and the various streams. The areas of these combined water surfaces was equal to 1.02 per cent. of the land surfaces. The construction of artifical storage reservoirs has since increased the area of water surfaces. Three reservoirs were completed and filled in 1879, making the total area of water surfaces after this date, until 1886, 2.31 per cent. of the land surfaces. In 1886, Reservoir No. 4 was added, increasing the per cent. of water surfaces to 2.92. The dryest periods occurred between the years 1879 and 1886, and it may therefore be assumed that the water surfaces which had the most effect upon the present records were 2.31 per cent. of the land area.

The flow of the river past the lowest dam has been greatly modified by the use of the artificial reservoirs; but this does not appear in the records, because the amount flowing past the dam is corrected by the amount added to or drawn from storage. The object in making these corrections has been to eliminate the effect of the reservoirs and to present in the records the natural flow of the stream modified only by such storage as is furnished by ordinary mill ponds and by Whitehall Pond. It cannot, however, be said that the effect of the reservoirs is wholly eliminated, because the evaporation from the increased water surfaces is not taken into account; and the dry weather flows recorded are consequently less than they would be if these reservoirs did not exist.

The average annual rainfall upon the Sudbury River water-shed is 45.8 inches, which is nearly the same as in the other parts of Massachusetts, so that, within the state, it is not often necessary to take account of differences in the amount of the rainfall.

The water-shed of the Sudbury River contains many hills with steep slopes, some of which are used for pasturage and others are covered with a small growth of wood. The valleys, as a rule, are not steep, and there are extensive areas of swampy land, generally covered with a growth of brush and trees. The hills are, for the most part, of rather impervious clayey material, containing boulders, while the flat land is sandy and in some cases gravelly.

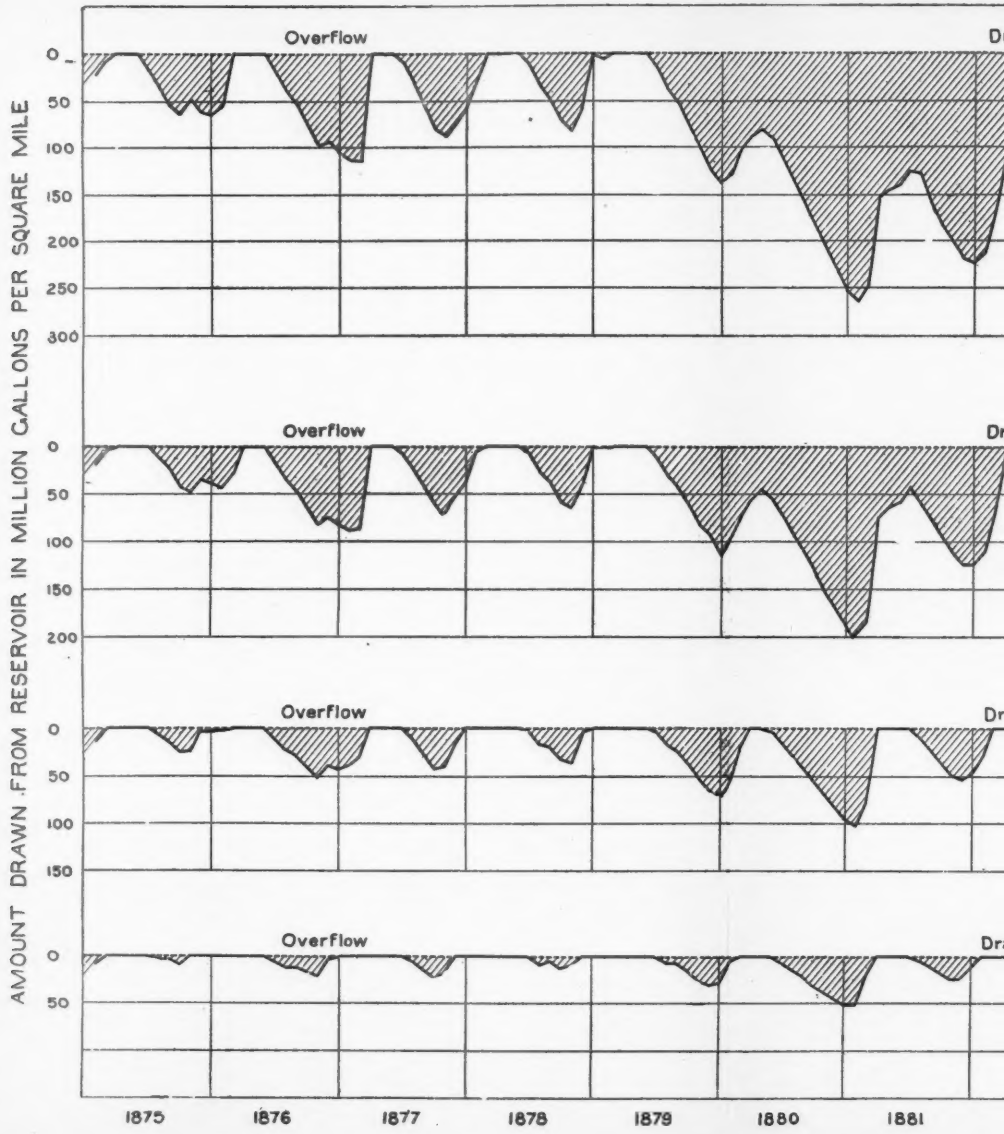
The supply to be obtained from a given water-shed will not always be governed by the quantity of water which can be stored, because considerations of quality require that the levels of the reservoir should not be made to fluctuate too much, and that the reservoir should not be drawn below high water mark for too long a time.

The diagram given opposite has been prepared from the Sudbury River records to show the fluctuations of a reservoir from which 400,000, 600,000, 800,000 and 900,000 gallons of water per day per square mile are drawn. The dotted lines marked "overflow" represent the full reservoir. The shaded areas indicate a draught upon the reservoir, the amount of which in gallons of storage per square mile is shown on the diagram. It will be seen that a consumption of 800,000 or 900,000 gallons per day per square mile causes a reservoir to be drawn below high water mark for many years at a time, which could hardly be permitted except in the case of a natural pond with gravelly shores.

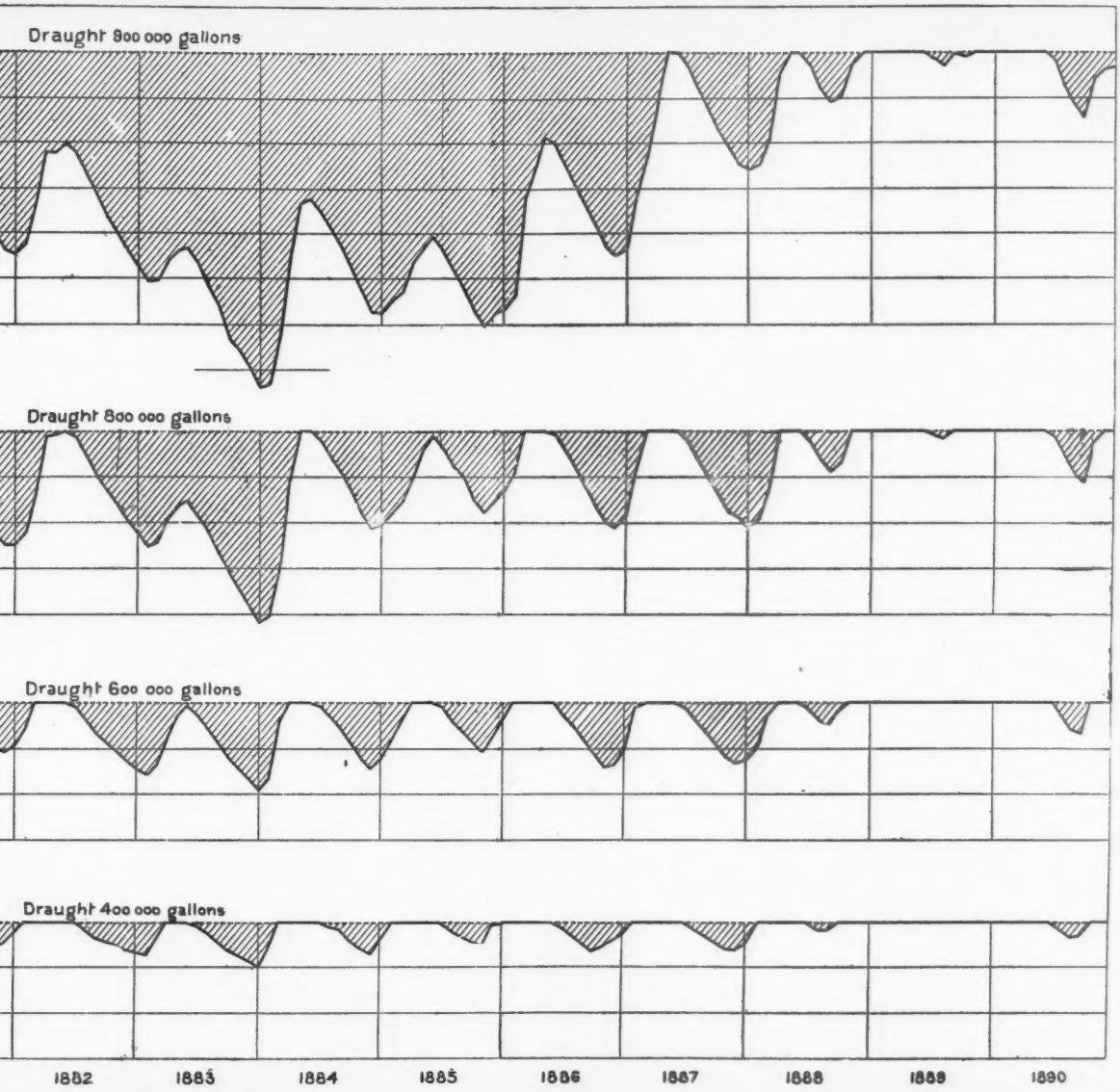
The only point remaining to be considered with regard to the quantity of surface water relates to the flow from water-sheds during short periods of extreme drought. The flow during such periods is chiefly of importance when it is desired to know the minimum flow of streams on which little or no storage can be obtained. On such water-sheds the water surfaces are generally insignificant, so that the Sudbury River records are not applicable unless they are corrected for evaporation. It is well known that the natural dry-weather flow of streams per *square mile* depends much upon the *extent* of the water-shed, because it is frequently observed that streams draining but a small area dry up in summer, while those draining large areas continue to flow, though with a greatly reduced volume. There is also a large variation in the dry-weather flow from water-sheds of the same size due to the amount of water stored in the ground and subsequently coming out in the form of springs. The records of the natural flow of streams in a very dry period are very meagre. The lowest flow of the Sudbury River occurred during the month of September, 1884, and averaged only 44,000 gallons daily per square mile of water-shed. Correcting for the excess of evaporation from water surfaces over the rainfall upon them, we obtain 97,000* gallons per square mile as the amount that the flow would have been if there had been no water surfaces. The next lowest monthly

*This quantity is somewhat larger than it should be as no account is taken of the water which came from the ground adjoining the reservoirs as they were being drawn down to supply the city.

DIAGRAM SHOWING THE FLUCTUATIONS OF A RESERV
AND 900,000 GALLONS PE



ERVOIR CAUSED BY A DAILY DRAUGHT OF 400,000, 600,000, 800,000,
PER DAY PER SQUARE MILE OF WATERSHED.



record was in September, 1877, 60,000 gallons per square mile. At this date the reservoirs had not been constructed and the area of water surfaces to which the corrections for evaporations should be applied was smaller. Making the correction we have as the flow per square mile 82,000 gallons per day.

In the report of the Water Commissioners of the Pittsfield Fire District, dated April 1, 1887, it is stated that on September 10, 1886, at the end of a somewhat extended drought, it was found by a careful measurement that 446,000 gallons were flowing daily in Sackett Brook and in Ashley Brook below the Ashley Reservoir, at a time when no water was overflowing from the reservoir. The area from which this water flowed is found by measurement from the topographical map of the State to be 5.3 square miles; consequently the flow equals 84,000 gallons per square mile. This drainage area is mountainous, and contains no water surfaces except the streams.

In the report of the Board of Water Commissioners of Northampton for the year ending Feb. 1, 1883, a measurement of Roberts' Meadow Brook in August, 1882, is recorded. The volume, when the stream was at its lowest point, was 450,000 gallons in twenty-four hours. The area of the water-shed is 10.6 square miles; hence the flow per square mile amounted to 42,000 gallons per day. This water-shed has steep slopes, and contains no ponds or reservoirs of any importance.

On August 8, 1890, I measured the flow of Beaver Dam Brook, one of the feeders of Lake Cochituate, and found the volume of water flowing to be 221,000 gallons per day. The measurement was made at the point where the brook first crosses the road between Natick and South Framingham. The area of the water-shed of the brook above this point, as taken from the topographical map of Massachusetts is 5.82 square miles, making the daily flow per square mile 38,000 gallons. This water-shed contains Waushakum Pond, which has an area of 87 acres and a very large area of meadow and swampy land.

It should be remarked with reference to the figures which have been given that the Sudbury River records represent the average flow for a month, while the other measurements represent the flow at one time only. On the other hand the Sudbury River measurements represent the dryest periods occurring in sixteen years, while the other measurements, although taken at times of very low flow, do not probably represent the dryest periods which have occurred.

Judging from the few measurements which are available it seems fair to infer that the minimum flow from a square mile of water-shed without storage will not, under favorable conditions, exceed 80,000 gallons daily; and that under conditions frequently met with the flow may not be more than half of this amount; or with very small water-sheds it may be nothing at all, as in the case already cited of streams which run dry in summer. These statements do not, however, apply to the larger streams in Massachusetts, such as the Connecticut, Merrimack and Chicopee rivers, which have a large minimum flow.

QUANTITY OF GROUND WATER.

It has already been stated that ground water supplies are much more limited as regards quantity than surface waters, and that the amount to be obtained at any given place cannot be as accurately predicted. There are, however, many examples in Massachusetts which show that the towns and smaller cities can obtain a sufficient supply of ground water where the local conditions are favorable; for instance, the city of Newton, with a population in 1890 of 24,379, obtains a ground water supply, and has recently been extending its works with a view to supplying a much larger population.

The statement that the quantity of ground water cannot be as accurately predicted as the quantity of surface water should not lead to the inference that the quantity of ground water to be obtained from any given source is chiefly a matter of guess work, because it is feasible in most cases as a result of experience and calculation to determine with a moderate degree of accuracy the quantity of ground water which can be obtained from a given source.

In the case of ground waters as in the case of surface waters the supply is dependent upon the rainfall. It may be the rain which falls in the vicinity of the source and filters directly through the ground to it, or it may be that which finds its way into the streams and then filters through the bottom of the stream into the ground near the source from which the supply is taken; but it rarely happens that the supply comes from the rain which falls far outside of the direct water-shed of the source or of the stream near it.

In a large majority of cases ground water supplies are taken from large wells, tubular wells, filter-galleries or filter-basins situated in the low lands adjacent to some large stream or pond. There are many instances, however, in which the supply is taken from a locality where no water comes by filtration from a stream or pond, and the whole supply is consequently rain water which filters into and through the ground to the point from which the water is taken. These two classes of ground waters require a somewhat different consideration; and the latter, in which a supply is taken from what may be called the direct water-shed of the well,* will be considered first.

In this case the conditions are in some respects similar to those which obtain in the case of surface water supplies; that is, the size of the water-shed, the proportion of the rainfall which will filter into the ground, and the amount of available storage in the interstices of the ground in the vicinity of the well are important factors; and there is in addition a factor which does not appear as prominently in the case of surface water supplies, namely, the porosity of the ground.

Statistics regarding the proportion of the rainfall which will filter into the ground are very few, but it is obvious that much less will enter the ground where the surface is sloping and nearly impervious than where it is flat and porous. Probably the most favorable water-shed which can be obtained is one which is generally level and gravelly and contains numerous depressions

*For convenience the term "well" will be used to designate all kinds of constructions for obtaining water from the ground.

having no outlet, so that all the water from the rainfall which is not lost by evaporation goes of necessity into the ground. Much of the water-shed of the Mansfield source of supply is of this character. Under these most favorable conditions it seems probable that the quantity of water which passes into the ground will not vary much from that which flows over the surface and underground from the same area of water-shed into a stream. We may, therefore, for the present, estimate that the quantity of water which can be collected from the water-shed of a ground water source will not in any case *exceed* the amount to be collected from an equal area of water-shed of a surface water source, and that generally it will be less by the amount which runs off over the surface.

There is a common tendency to over-estimate the quantity of water which can be obtained from the ground in a locality where nature has already provided a free flowing spring, or where flowing test wells have been driven ; but estimates based upon the size of the water-shed draining toward the spring or well will often show how incorrect these estimates are.

Although a sufficient water-shed is essential, it is equally essential that the ground should be porous enough to permit the required quantity of water to flow through the ground into the well.

In many cases where the supply required is not very large sufficient information as to the porosity of the ground can be obtained by driving test wells and determining the character of the strata penetrated. Some additional information may also be obtained by pumping from these wells with a hand pump. In order to predict the quantity of water which will flow into a well, after the character of the material is known, it is necessary to depend upon the experience obtained from existing wells in similar situations. Some information bearing upon this subject is given in the table opposite page 119.

In cases where a larger supply is necessary, or where the results of the tests above mentioned are not sufficiently definite, it may become desirable to make a more complete test, which is generally done by driving a large number of test wells, connecting them all with a single suction pipe and pumping from them.

A test of this character is generally intended to show not only the porosity of the ground, but also to indicate the amount of storage which is available, and the distance from which the ground water may be drawn to the wells when the water in the vicinity is lowered by long-continued pumping in a dry time. Records are kept of the height of the ground water in the immediate vicinity of the test wells and for a considerable distance from them in all directions. For this purpose frequent observations are made of the level of the water in existing wells which may be affected by the pumping, and where these do not exist in sufficient number additional test wells are driven to give access to the ground water.

A test of this kind should be made during as dry a period as possible; but even then the quantity pumped is not necessarily the safe capacity of the source, and the test has its greatest value in the opportunity it affords the engineer of determining the storage capacity of the ground, and the extent of the area from which the rainfall may be expected to filter toward the well. With

the information obtained by such a test made in the dryer portion of an ordinary year it is feasible to estimate with a moderate degree of accuracy the safe capacity of a source in a dry year. A test of this character, lasting three months, was made at Eaton's Meadows, Malden, in 1887-88, before constructing the permanent works at that place.

It is sometimes feasible in the case of a proposed ground water supply to determine whether the source is worthy of careful investigation by means of the table given on page 112, for determining the volume of surface water obtainable with different amounts of storage. If, for instance, it is desired to obtain a supply of 300,000 gallons per day, and the water-shed draining toward the proposed well is one square mile, we find from the table that in the case of a surface water supply the storage, when there are no water surfaces, must be 29,800,000 gallons. If the supply is to be taken from the ground it seems fair to assume that at least an equal amount of storage will be required; and the question to be considered relates to the probability of obtaining this amount of available storage, which is equivalent to the contents of a pond having an area of ten acres and a depth of nine feet. Porous gravel or sand when saturated contains in the neighborhood of thirty-five per cent. of water, but of this a portion remains after the ground is drained, so that only about twenty-five per cent. of the whole mass will run out when the water table is lowered. Therefore, in order to obtain 300,000 gallons daily from a square mile during the dryest period, it is necessary to have a storage equivalent to that furnished by forty acres of porous gravel in which the water table can be lowered nine feet. A superficial examination of the ground may show whether it is probable that this amount of storage can be obtained, and in this way indicate whether it is desirable to make further investigations.

In the case of wells located near a large stream or pond there is always a direct water-shed, the yield from which is to be obtained by the methods already indicated; but if this does not supply a sufficient quantity of water a greater or less amount will also filter from the stream or pond as soon as the adjacent ground water is lowered below the level of the surface water. That much water may come from a stream or pond and still have the characteristics of ground water is definitely shown in the case of the filter-gallery near Horn Pond, in Woburn, where the pond contains an abnormal amount of chlorine,* owing to entrance of the tannery drainage which contains much salt; and the filter-gallery water also has an abnormal amount of chlorine which cannot be attributed to any other source than the pond. There are many other instances in the State where there are strong indications that a large portion of the supply comes from the neighboring river or pond, showing that the Woburn case is not an exceptional one.

No definite figures have been obtained of the amount of water which will filter through river or pond bottoms, but it is known that they get silted up so that the amount of water which will pass through per square foot is small, and it is consequently necessary to have a large area of river or pond bottom

*The normal chlorine of the region, is 0 33; the average chlorines of the filter-gallery and pond for three and one-half years are, respectively, 2.20 and 2.57.

1 CITY OR TOWN.	2 Population in 1890.	3 Date of Construction.	4 DESCRIPTION OF WORKS.	5 Adjacent Stream or Pond.	6 Approximate Area of Direct Water-shed of Well or Filter-gallery. Square Miles.	7 Area of Water-shed of stream or pond near Ground-water Source. Square Miles.	Char
Amesbury (original source)	9,798	1865	Well 20 feet in diameter and 50 feet deep, thirty-six 2-inch tubular wells 45 feet deep.	Very small stream	—	—	Clay, g
Amesbury (new source)	—	1886	Two open basins each about 80x40 feet. The basin from which most of the water is taken is 14 feet deep, and has fourteen 2-inch tubular wells extending 16 feet below its bottom.	None	—	—	Gravel
Attleborough	7,577	1873 1882	Well 13 feet in diameter, bottom 5 or 6 feet below bottom of river; filter gallery 3 feet wide, 3 feet high and 100 feet long; five 2 inch, two 1¼ inch, and one 3-inch tubular wells driven in well and gallery 34 feet below bottom of well.	Ten Mile River	—	21.10	Loam,
Ayer	2,148	1887	Well 25 feet in diameter at bottom, 25.7 feet deep.	Large Mill Pond	—	4.74	Gravell
Bradford	3,720	1890	Eight wells on Porter's Island, in the Merrimack River, about 100 feet from the shore; three of them 12 feet square, and five 12x24 feet; all 20 feet deep.	Merrimack River	—	4,819.00	About 1 grave
Braintree	4,848	1887	Filter gallery 110 feet long, 15 feet wide and 13.5 feet high; bottom 16.5 feet below high water in Little Pond.	Little Pond	0.12	0.55	Coarse,
Bridgewater East Bridgewater	4,249 2,911	1888 1889 1890	Two wells built first, one 60x20 and 17 feet deep, the other 20 feet in diameter and 18 feet deep. The third well, built in 1889, is 10 feet in diameter and 33 feet deep In the bottom of this is a 6-inch tubular well 86.5 feet deep. The fourth well is tubular, 202 feet deep, sunk in 1890. Water is also drawn from a spring near the wells.	Town River	0.32*	55.82	About 1 ledge.
Brookline (excluding extension)	12,103	1875	Filter gallery in two sections, 491 and 571 feet long, connected by a conduit 380 feet long. From 4 to 6 feet in width and height.	Charles River	—	134.20	Gravel
Brookline (including extension)	—	1875 1890	The extension made in 1890 consists of forty-four 2½-inch tubular wells, averaging 35 feet in depth, included in a length of about 2,500 feet.	Charles River	—	134.20	Tubular muck
Canton	4,538	1889	Well 40 feet in diameter and 25 feet deep; twelve 2-inch tubular wells in the vicinity are connected by siphon.	Beaver Brook	0.24*	2.47	Close cl
Cohasset	2,448	1886	Sixty-one tubular wells, each 2 inches in diameter and 30 to 40 feet deep, included in an area 725 feet long and 90 feet wide.	Small Brook	—	0.42	Sixteen clay,
Dedham	7,123	1881	Well 26 feet in diameter, 18 feet deep, situated 40 feet from the river.	Charles River	0.15*	194.01	Sand an
Easton	4,493	1887	Well 29 feet in diameter at the top and 27 feet at the bottom; 26 feet deep.	Queset River	0.14*	4.22	Clayey
Framingham	9,239	1885	Filter-gallery at edge of pond 450 feet long, 3½ to 4 feet wide and 4 feet high; bottom of gallery 6 feet below surface of pond.	Farm Pond	0.10	—	Coarse
Franklin	4,831	1884 1887	Two wells, one 20 feet in diameter and 25 feet deep; the other 33 feet in diameter and 18 feet deep.	Mine Brook	—	7.68	Gravel
Grafton	5,002	1886	Filter gallery 95 feet long, 12 feet wide and 17 feet high; bottom is 20 feet below surface of ground.	Quinsigamond River	—	35.05	Three fe tom o
Hopkinton	4,088	1884	Three tubular wells each 6 inches in diameter, 59, 65 and 75 feet deep, near summit of a large hill. Wells included in a distance of 260 feet.	None	Very small.	—	From 3 broke
Hyde Park Milton	10,103 4,278	1885	One hundred and thirty-two 2-inch tubular wells 34 to 38 feet deep included in an area about 1,000 feet long and 150 feet wide.	Neponset River	0.46*	94.80	Porous
Kingston	1,659	1886 1888	Well 20 feet in diameter. Filter-gallery 360 feet long, 20 inches wide and 14 inches high.	Jones River	—	22.24	
Lexington	3,197	1884	Four large wells, also 8-inch tubular well 190 feet deep, all but 14 feet in rock.	Vine Brook	Very small.	0.60	Wells s rock...
Malden	23,031	1889	Fifty-one 2-inch tubular wells, sunk to an average depth of 65 feet, included in an area 100 by 300 feet.	None	1.61†	—	Wells su averag gravel

* Very rough approximation.

8	INFORMATION REGARDING CAPACITY OF SOURCE.						15
	Pumping Records.				Estimated Capacities.		
Character of the Ground in which Works were built.	9 Maximum Year. Gallons per Day	10 Maximum Month. Gallons per Day,	11 Maximum Week. Gallons per Day.	12 Maximum Day. Gallons per Day.	13 Dry Season. Gallons per Day,	14 When Ground is Filled with Water: Galls. per Day.	REMARKS.
Clay, gravel at bottom	—	—	—	—	100,000	—	No pumping records. Source would not furnish over 80,000 or 100,000 gallons per day and was abandoned.
Gravel and some clay	—	—	—	—	400,000	—	No pumping records. Average consumption about 175,000 gallons per day.
Loam, gravel, quicksand, and at bottom gravel	—	—	—	—	200,000 to 300,000	200,000 to 300,000	No pumping records. An additional supply is contemplated.
Gravelly 18.7 feet, then rock	62,262	85,786	—	—	—	—	Soon after the works were constructed the capacity was estimated at 10,000 gallons per hour, equal to 240,000 gallons per day.
About 16 feet of river silt, then 1 to 4 feet of gravel, then clay	—	—	—	—	250,000	300,000 to 400,000	No pumping records. About 250,000 gallons per day were pumped in the summer of 1891. Three additional wells are being built.
Coarse, porous gravel	215,629	361.801	—	557,287	—	—	
About 15 feet of clay, then 3 feet of gravel, then ledge	94,263	131,775	161,543	173,145	—	—	Wells to furnish an additional supply are contemplated.
Gravel and coarse sand	863,509	1,258,999	—	—	750,000	—	
Tubular wells sunk through about 25 feet of peat, muck and quicksand into porous gravel	964,873	1,258,999	1,436.137	1,829,680	1,500,000	4,000,000	
Close clayey gravel, very hard at bottom	79,106	—	143,126	224,136	250,000	600,000	The 224,136 gallons were obtained by pumping out practically all of the water in the well.
Sixteen to 25 feet of muck, clay, sand, and blue clay, then gravel at bottom	61,974	114,708	160,507	346,150	—	550,000	
Sand and coarse gravel	224,814	336,567	400,843	55 240	900,000	1,500,000	
Clayey gravel	101,771	125,367	161,233	248,660	—	—	A small storage reservoir has been constructed in the valley just above the well.
Coarse and fine sand	239,248	418,655	496,735	578,397	1,000,000	1,000,000	Supplies only South Framingham and a part of Framingham Centre.
Gravel for 8 feet, then ledge	90,575	140,630	—	253,800	300,000	600,000	
Three feet of peat; below that blue gravel to bottom of gallery, then ledge	—	—	—	138,000	—	1,000,000	An artesian well 6 inches in diameter and 97 feet deep was sunk 1889, but not connected with the works until July, 1891.
From 3½ to 18 feet of clay and gravel; then rock broken by seams	Estimated 40,000	—	Estimated 60,000	Estimated 70,000	40,000	125,000	An 8-inch well, 119 feet deep, has been added, but is not included in making these estimates.
Porous gravel	437,534	610,000	800,000	940,800	—	—	
— —	—	—	—	—	—	170,000	
Wells sunk through peat and hard pan into rock	Estimated 90,000	—	—	—	—	—	In a dry time a part of the supply has to be taken from supplementary sources.
Wells sunk through peat, clay and compact sand, averaging 55 to 60 feet in depth, into porous gravel	747,446	940,403	1,041,881	1,172,592	500,000	1,200,000	There is an additional area of watershed of 1.5 square miles, which is possibly tributary to the wells under certain conditions.

† The area contributing to this source varies with the amount of water pumped. The figure given is an engineer's estimate of the area tributary to the wells under normal conditions.

1 CITY OR TOWN.	2 Population in 1890.	3 Date of Construction.	4 DESCRIPTION OF WORKS.	5 Adjacent Stream or Pond.	6 Approximate Area of Direct Water-shed of Well or Filter-gallery. Square Miles.	7 Area of Water-shed of stream or pond near Ground-water Source. Square Miles.
Mansfield	3,432	1868	Well 25 feet in diameter and 20 feet deep, 625 feet from the river.	Canoe River	—	4.35
Middleborough	6,065	1885	Well 26 feet in diameter and 22 feet deep, 100 feet from the river.	Nemasket River	—	60.90
Newburyport	13,947	1881	Two wells, one 20 feet diameter and 18 feet deep; the other is smaller. A small storage reservoir fed by springs is near the wells.	Merrimack River	—	—
Newton (excluding extension made in 1890)	24,379	1876 1886	Filter basin 1,575 feet long, 10 feet wide at bottom, 58 to 75 feet wide at high-water mark; bottom 10 feet below water in river. Eight tubular wells in bottom of basin, 1½ to 4 inches in diameter; also four 6-inch and four 4-inch tubular wells on opposite side of river.	Charles River	—	140.50
Newton (including extension made in 1890)	—	1876 1886 1890	The extension made in 1890 consists of one hundred and seventy-four 2½ inch tubular wells from 21 to 130 feet deep, connected with a wooden conduit 2,952 feet long and 4 feet area in section; 732 feet of this conduit replace an equal length of filter-basin.	Charles River	—	140.50
North Attleborough	6,727	1884	Well 30 feet in diameter and 26 feet deep; 470 feet from Whiting's mill pond.	Whiting's Mill Pond on Ten Mile River	—	4.30
Revere Winthrop	5,668 2,726	1884	One well 30 feet in diameter, 20 feet deep, with three 6-inch and two 2-inch tubular wells in the bottom. Another well, 40 feet in diameter and 20 feet deep, with one 8-foot well, 30 feet deep, and eight 2-inch tubular wells in bottom. Also one hundred 2-inch tubular wells in the vicinity, comprised in a triangle whose sides are 1,100, 1 300 and 550 feet in length.	Small stream	0.78‡	0.67
Stoughton	4,852	1886	Well 25 feet in diameter and 30 feet deep.	None	0.23*	—
Swampscott Nahant	3,198 880	1885	Well 22 feet in diameter and 20 feet deep, 35 feet from brook, with six 2-inch tubular wells in bottom, driven 50 to 75 feet. Supplementary supply from seventy-two driven wells about 40 feet deep, near the brook above the large well.	Stacy's Brook	—	2.62
Taunton	25,448	1876	Filter-basin 400 feet long, 17 feet wide at bottom; bottom 8 feet below low water in river. Filter-gallery 863 feet long, 5 feet 9 inches in height, 4 feet in width; bottom level with filter-basin. Two tubular wells sunk in bottom 25 to 37 feet deep. Filter-bank 94.6 feet long, 40 feet wide at bottom, 10 feet high.	Taunton River	—	312.40
Tisbury	1,506	1887	Filter-gallery 38 feet long, 7 feet wide at bottom, 10 feet high.	Lake Tashmoo		—
Waltham	18,707	1873	Filter-basin of irregular shape, having an area of about one-fourth of an acre. Bottom is 8.5 feet below the average level of water in the river.	Charles River	1.11§	181.00
Ware	7,329	1886	Well 26 feet in diameter and 22 feet deep.	Muddy Brook	0.37*	19.44
Watertown Belmont	7,073 2,098	1885 1889 1890	Filter-gallery in three sections: 90 feet long, 15 feet wide; 175 feet long, 5 feet wide, and 2 feet high, 102 feet long and 8 feet wide. The last is at right angles to the other two, and all are on a level. In 1889, twenty 2-inch tubular wells were added. In December, 1890, a well 20 feet in diameter and 24 feet deep was completed.	Charles River	—	197.80
Wellesley	3,600	1884	Filter-gallery 63 feet long, 11 feet wide at bottom, and 17. feet deep. Large well 22 feet in diameter and 20 feet deep at Williams' Spring.	Rosemary Brook	—	4.28
Whitman	4,441	1883	Filter-gallery built in two sections. First section 100 feet long, 15 feet wide, and 14 feet deep; bottom is about 12 feet below high water in the pond. Second section 416 feet long, 18 inches wide, and 20 inches high.	Hobart's Pond	0.06*	6.40
Woburn	13,499	1873	Filter-gallery 82 feet long and 12 feet wide, with side walls 9 feet in height, surmounted by a brick arch. The bottom of the gallery is about 8 feet below high water in the pond.	Horn Pond	0.21	7.44

* Very rough approximation.

‡ This area includes the whole water-shed of the brook opposite the wells and some territory below the wells, which probably contributes water to them.

8	INFORMATION REGARDING CAPACITY OF SOURCE.						15
	Pumping Records.				Estimated Capacities.		
Character of the Ground in which Works were built.	9 Maximum Year. Gallons per Day	10 Maximum Month. Gallons per Day.	11 Maximum Week. Gallons per Day.	12 Maximum Day. Gallons per Day.	13 Dry Season. Gallons per Day.	14 When Ground is Filled with Water: Galls. per Day.	REMARKS.
Porous gravel	137,968	179,866	—	395,170	—	—	The maximum day's pumping lowered the water in the well 4.5 feet. The amount pumped during construction in a very wet season was estimated at 3,000,000 gallons.
Coarse, loose gravel	142,730	205,935	247,428	389,000	1,000,000	2,000,000	In July, 1888, when the stand-pipe was shut off for ten days, and continuous direct pumping was resorted to, about 500,000 gallons were pumped daily and the ground water lowered but little more than a foot.
Porous gravel	443,047	503,818	564,490	649,359	—	—	
Filter-basin in fine gravel, sand and quicksand, Tubular wells sunk to coarse sand or gravel	918 013	1,218,387	—	4,747,000	1,050,000	—	These works in 1886 furnished 1,050,000 gallons per day after pumping for six weeks in very dry weather.
The 174 2½-inch wells are sunk in material varying from porous gravel or coarse sand to quicksand or hard pan	1,041,616	1,400,419	1,699,285	—	2,000,000	6,000,000 to 8,000,000	
Through quicksand to gravel	166,575	—	336,535	435,690	500,000	—	
Through clay to gravel, which is reached at from 50 to 75 feet beneath the surface	465,491	680,411	726,210	1,066,395	560,000	2,000,000	The estimated yield of this source in a dry season (560,000 gallons) is a little less than the amount actually pumped in August, 1891. So large a draught, however, could not be continued during the whole of an ordinary year without exhausting the supply.
Ledge except near the surface of the ground	—	—	—	—	—	—	Average daily consumption, estimated at 50,000 gallons per day, requires about all of the water that the well will supply.
Loam at surface, then blue clay from 5 to 28 feet, with coarse gravel beneath	254,653	691,788	648,943	1,015,050	400,000 to 600,000	1,200,000	A large portion of the water of Stacy's brook is diverted into the Lynn intercepting sewer.
Boring at west end of basin showed 10 feet of sandy gravel, 10 feet of sand mixed with clay, 20 feet of clay, 10 feet of clay mixed with fine gravel, 2 feet of fine gravel, 35 feet very hard blue clay, with granitic sandstone beneath	918,137	1,143,686	1,214,358	1,563,738	1,000,000	3,500,000	There is a direct connection with Taunton River, and this water is used when the supply is insufficient. It is estimated that during the days of maximum consumption from one-third to one-half of the water pumped is drawn from the river.
Sand	—	—	—	—	—	—	The gallery can be pumped out in three hours with a pump having a capacity of 1,000,000 gallons in 24 hours, and will fill again in about 45 minutes.
Porous gravel	687,749	943,737	1,243,469	1,518,200	1,100,000	—	Works are now being built to increase the supply of water.
12 feet of clay, then coarse gravel	179,676	260,040	292,449	462 900	864,000	1,000,000	
1 to 1.5 feet of loam, 15 feet of coarse gravel, about 45 feet of fine sand with ledge beneath	361,213	530,600	597,857	1,302,500	1,000,000	5,000.000	
The filter-gallery is built in a compact hard-pan. The well at Williams' Spring is in loose gravel	257,875	335,051	357,603	463,200	—	—	The amount that could be obtained from this source in a dry year is probably less than is being used at present. Fully three-fourths of the water now comes from the well at Williams' Spring.
A hard clay through which water filters very slowly. Ledge is found 20 to 25 feet beneath the surface	103,276	175,494	266,229	451,635	Without drawing from pond 125,000	175,000	A direct connection with the pond is used in order to obtain a sufficient supply whenever the amount furnished by the well is too small.
Porous gravel	951,589	1,137,424	1,172,850	1,308,300	1,300,000	4,000,000	

§ This area, including territory on both sides of the river, is probably in excess of that which has contributed to the supply in the past.

in the vicinity of the ground water source to obtain a large amount of water by this kind of filtration.

With regard to the form of construction used, it may be said that no one method is applicable to all cases. Where the material is coarse and porous within a short distance of the surface and the quantity of water required is not very large, a circular well covered to exclude the light is generally the best. In other instances, where the material for a long distance from the surface is impervious, but is underlaid with pervious material, it is impracticable to excavate a large well to the required depth, and it becomes necessary to sink tubular wells down to the porous stratum which may sometimes be found overlying the solid rock. An instance of this kind is found at Malden where the average depth of the wells is sixty-five feet. There are also other instances in which driven wells are used to obtain water from a larger territory than would be influenced by a single large well.

Tubular wells may be connected by means of a large suction-pipe directly with the pump, which is generally the cheaper form of construction, or they may be connected with excavated wells or filter-galleries, into which the water from the driven wells will flow.

Filter-galleries are built in some instances where it is desired to intercept the ground water from a greater extent of territory than will be influenced by a single well. They are in fact elongated wells, except that, in practice, on account of the cost, they are not usually sunk to as great a depth.

Filter-basins perform the same office in collecting water as wells and filter-galleries, but being uncovered, the water in them deteriorates, owing to the rapid growth of vegetable and animal forms which flourish in this kind of water when the light is not excluded. This form of construction should therefore be avoided.

There are many instances in which the main supply comes from wells and filter-galleries, but is increased by means of driven wells extending from them into porous strata at lower levels.

In addition to the ordinary driven wells already referred to, which are limited in depth to from thirty to ninety feet, and do not in any case penetrate the rock, attempts have been made in several parts of Massachusetts to obtain a large supply of water by sinking wells six or eight inches in diameter into the rock to a depth of several hundred or even several thousand feet. The result has been in nearly every case unsatisfactory, and in no way comparable with the results obtained from comparatively shallow wells in porous material.*

The information heretofore published with regard to the quantity of water which can be obtained from wells and filter-galleries variously situated is very meagre. With a view of obtaining additional light upon the subject a circular has been sent to the places in Massachusetts having a ground water supply, asking for information with regard to the character of the works constructed for obtaining water, the nature of the ground, and the capacity of the source. Replies to the circular were received from 35 places, and the information thus obtained is given in a condensed form in the table opposite.

*Statistics of deep wells sunk in rock are given in a table on pp. 26, 27 of the Fourteenth Annual Report of the Water Commissioners of Taunton, Mass., Nov. 30, 1889.

The areas of water-sheds in columns 6 and 7 were obtained in most cases by sketching upon the topographical map of the State the outlines of the water-sheds and measuring the included area. In the case of the direct water-sheds (column 6), the results are for the most part only rough approximations, particularly those marked with an asterisk. The estimated capacities of sources as given in columns 13 and 14, were furnished by those connected with the various water works.

Before reviewing the tabulated information it may be well to call attention to the fact that comparatively few of the ground water supplies have been subjected to a severe test in a dry year like 1880 or 1883, because a large number of them were constructed since that time; and of those constructed at an earlier period the greater number had then been in use so short a time that the draught upon the works was not excessive.

The average yield of the Sudbury River water-shed per square mile during the year 1880 was 580,000 gallons per day and for the four years ending in 1883, 738,000 gallons. In contrast with this we have as the yield in 1887 (the dryest of the four years ending in 1890), 1,154,000 gallons per day per square mile, and as the average yield for the whole four years, 1,381,000 gallons. These figures, showing that the yield of water-sheds during the last four years, has been very nearly twice as large as during the dry period of four years ending in 1883, make it evident that records and estimates obtained from sources which are being used nearly up to their full capacity in these comparatively wet seasons will tend to show that the sources will furnish more water than they can be depended upon to furnish during a prolonged drought. In other cases, where only a small part of the capacity of the works is now being used, it is obvious that the pumping records are of value only as showing that the sources will yield at least the amount given; but they do not in any way indicate the maximum capacity of the sources. The table must be used with discretion, but it is believed that when so used it will be of considerable value to those selecting sources of ground water supply.

The table represents so much variation in conditions and in value of data that it is hardly feasible to make any summary of it. It may be well, however, to call attention to a few prominent features.

The largest supplies, taken wholly from the ground, are as follows:

City or Town.	Average Daily Pumping, Maximum Year.
Newton, ...	1,041,616 gallons.
Brookline, ...	964,873 "
Woburn, ...	951,589 "
Waltham, ...	687,749 "

It is noticeable that these supplies are all taken from the ground in the vicinity of large bodies or streams of water. Newton and Brookline have re-

cently extended their works, which are now expected to yield, respectively, 2,000,000 and 1,500,000 gallons daily in a dry season. These estimates, made by engineers of long experience, are probably conservative, and may be said to represent the largest supplies of ground water yet obtained in this State. Waltham is now increasing the capacity of its source with a prospect of obtaining as much water as either Newton or Brookline. It is noticeable, however, that the ease with which these large quantities are obtained varies very much. At Waltham, it is expected to obtain the desired supply from a well 40 feet in diameter, while at Newton the works cover a total length along the river of about 4,300 feet. At each of these four places the ground water is kept pumped down below the level of the neighboring body of surface water, and there is reason to think that much of the supply is filtered surface water.

There are several supplies where a large amount of water is obtained from direct water-sheds, without being supplemented by filtration from surface water sources. As instances, the supplies of Malden, Newburyport and Revere may be mentioned.

The maximum amount pumped from these sources has been as follows:

City or Town.	Average for the Year. Gallons per Day	Average for the Month. Gallons per Day
Malden,	747,446	940,403
Newburyport,	443,047	503,818
Revere,	465.491	680,411

At Malden the amount pumped in 1890 represented a collection of 9.7 inches (or 20 per cent. of the total rainfall of 49 inches) upon a direct water-shed estimated at 1.61 square miles. At Revere, the pumping for the year ending June 30, 1891, represented a collection of 12.5 inches (25 per cent. of the total rainfall of 50 inches) upon a water-shed of 0.78 square miles. At all three of these places it is probable that the amount which has been pumped is more than could be pumped after one or two years of low rainfall. At Revere, particularly, experience has shown that the storage capacity of the ground is very large, so that when the water table is reduced to a very low level during the summer, the ground will not fill before the next summer unless the amount of rainfall is above the average.

It has already been mentioned that the amount of chlorine found in the water of the filter-gallery at Woburn, shows that a large proportion of the water comes from Horn Pond. A comparison of the amount pumped from the gallery with the precipitation upon the direct water-shed leads to similar conclusions. The amount pumped during the year ending August 31, 1887, was 951,589 gallons per day. The precipitation during the same period equalled 42.3 inches, which upon the direct water-shed of 0.21 square miles was equivalent to 423,000 gallons per day. The amount which can be collected is much

less than the total precipitation. If we use the proportion collected at Revere (25 per cent.) as a basis, the yield from the direct water-shed at Woburn during the year mentioned would have been 105,750 gallons per day or about one-ninth of the amount actually pumped.

As instances of supplies where ground water is obtained only in small quantity, in proportion to the extent of the works, we may mention those at Lexington and Bridgewater.

At Lexington, with four large wells and a deep tubular well, the supply obtained in a dry summer is less than 100,000 gallons daily. This is owing both to the small water-shed tributary to the wells, and to the unfavorable character of the ground for storing water in the wet season of the year where it will maintain the yield of the well in the dry season.

At Bridgewater, two wells, one very large, were completed in 1888, but the next year, when the consumption of water in summer was about 75,000 gallons per day, it was found advisable to add another large well with a deep six-inch tubular well in its bottom, and in 1890 a second tubular well was sunk. The works as they now stand do not furnish any very large excess above the present consumption of about 130,000 gallons per day in summer, so that a further extension of the works is contemplated. These instances are mentioned to show that works of considerable extent do not necessarily furnish much water, unless the ground is porous, and there is either a large direct water-shed, or a neighboring stream or pond to saturate the ground.

The returns show that, in Massachusetts, wells excavated in rock do not furnish large quantities of water.

QUALITY OF SURFACE WATER.

As indicated in the introduction to this paper the quality of water for the supply of a city or town has to be considered from several points of view. First and most important, it must not be injurious to the health of the community. Second, it must not have a disagreeable odor or be unpalatable. Third, it should not be too hard for washing and for use in boilers.

The most important factor in making water dangerous to the health of the community is the discharge of human sewage into it, whereby the germs of specific diseases may be introduced into the water. We may, therefore, say in general terms that a water will be dangerous to health in proportion to the density of population upon the water-shed from which the supply is derived. This statement, however, needs much qualification, because it makes a very great difference whether the sewage of the population enters the water directly or is filtered through the ground from cesspools; and, even in cases where sewage does enter the water more or less directly, the time which elapses between such entrance and the drinking of the water is a very important element. For instance, the discharge of the sewage of the city of Lowell into the Merrimack River, so that within a day it may reach the intake of the Lawrence water works, is a much greater menace to the health of the inhabitants of Lawrence than the discharge of a corresponding amount of sewage from Natick into the southerly division of Lake Cochituate (where the passage to the northerly division, from which water is drawn, requires months of

time) is to the health of the city of Boston. On account of this quicker transmission of the infectious matter by streams it seems fair to say, that, when polluted, they are more dangerous as sources of water supply than reservoirs and ponds.

Surface water may have a dark color owing to the drainage from swamps; or that flowing in streams may become turbid with suspended mineral matter after rains; or the water of reservoirs and ponds may be somewhat turbid and have a disagreeable taste and odor, owing to the presence of algæ and other minute organisms. It is the presence or absence of these features which can be recognized by the senses that generally determines the quality of water in the public mind. The organisms which produce the disagreeable tastes and odors are not the so-called disease germs, and the experience of cities and towns using waters which generally contain these organisms does not indicate that they have a noticeable influence upon the health of the community. When present in large numbers, however, they often make the water so disagreeable to the senses that it is unfit for drinking, and in this way are a great evil. They very rarely occur in abundance in the water of streams, but are more frequently abundant in stored waters. All stored waters, however, are not equally affected, the character of the water and the manner in which it is stored having an important influence upon the amount of these growths. Unpolluted deep ponds generally furnish a water free from bad tastes and odors, and deep storage reservoirs prepared by the removal of all of the soil and vegetable matter from the bottom and sides are equally satisfactory for the storage of water. The effect of density of population upon the water-shed is also found to be one of the most important factors in causing these troublesome growths, which develop in abundance where the water is supplied with nitrogenous matter from sewage and the animal manures produced or used in populous districts. The effect appears to be nearly the same when the sewage is purified by filtration through the ground before entering the water supply, as when it is discharged directly into it.

Experience shows that where the population exceeds 300 per square mile of water-shed, the stored water, whether contained in a natural pond or artificial reservoir, is particularly liable to produce an abnormal growth of organisms, and in consequence give trouble from bad tastes and odors. Shallow storage reservoirs from which the soil and vegetable matter have not been removed generally give trouble, and the large and deep reservoirs of the same character are by no means exempt.

The color of the water which enters the pond or reservoir does not appear to have a marked effect upon the growth of organisms. A water having much color generally has a noticeable taste caused by the vegetable matter in solution which produces the color. This taste, however, is not particularly disagreeable.

Natural waters from regions where limestone abounds are frequently too hard to be satisfactory, either for washing or boiler purposes, but, in Massachusetts, these conditions exist only in limited portions of the western part of the State. In the eastern portion of the State the natural waters are soft, and it is only through pollution that they become hard. There are, however, very

few surface waters, except in the extreme western part of the State, which are not suitable for washing and for use in boilers.

There are several ways in which the purification of surface water of unsatisfactory quality can be effected by artificial methods,—as, for instance, by filtration through sand; but this can only be done with considerable difficulty and expense. It is therefore the best plan, in selecting a surface water, to obtain one which will not require artificial purification. When water is taken from the ground near streams and ponds it is often to a large extent surface water so thoroughly filtered that it cannot be distinguished from the natural ground water. This method of purification by natural filtration is an excellent one to adopt where there is a sufficient area of porous ground adjoining the surface water source.

QUALITY OF GROUND WATER.

With ground waters as with surface waters, the quality must be considered from several points of view. First, the water must not be dangerous to health; second, it must be free from any bad taste, odor and appearance which will make it disagreeable as a drinking water; and third, it should be suitable for domestic and boiler uses. The danger to health comes, as with surface waters, from sewage pollution; but a ground water is not as liable to such pollution as a surface water, because during the passage of the water to the well both the suspended and soluble organic matters, including the bacteria, are to a very large degree retained by the ground or oxidized into harmless inorganic compounds.

As a result of this purifying action, ground water draining from a territory which has upon it considerable population (provided it is not too near the well) is as pure as most surface waters draining a territory much less thickly populated. This statement is not intended to encourage the location of ground water sources where they will obtain their supply from a populated district, because such action is not advisable where an entirely uncontaminated source can be obtained, even at a large additional expense, and it is only where such a supply cannot be obtained that the relative merits of supplies from even slightly polluted territory should be considered.

It may be well in this place to call attention to the great difference which usually exists in the quality of water from public and private wells. The former are usually located at a considerable distance from any habitation, so that even if they draw polluted water from populous districts it has to pass a long distance through the ground before reaching the well, and is generally diluted by a large amount of water from other directions entirely free from pollution; and these public wells are also as a rule, thoroughly protected from the entrance of surface washings or the accidental entrance of other foul matters. The typical private well in a village, on the other hand, often receives a considerable portion of its water from cesspools located so near it that the polluted water does not become at all thoroughly purified by its passage to the well, and the direct entrance of surface and other dirty water and foul matters is not wholly prevented.

In the foregoing statements we have had in mind sources which derive their supply from what we have before called the direct water-shed. In the case of sources which obtain their supply by natural filtration from a neighboring stream or pond, the conditions are somewhat different. Even where the color, taste and odor are so completely removed that these filtered waters cannot be distinguished from the true ground waters, the removal of the organic matter (and probably of the bacteria) is not quite as complete as in the cases of the slower and to some extent intermittent filtration from the land side. If, however, we refer to the examples furnished in Massachusetts, we find in most instances that the surface waters before filtration are contaminated so little, that after being converted into ground waters by filtration they are about as good from a health standpoint as true ground waters which more frequently derive their supply from populous districts.

There is another class of waters obtained by natural filtration from streams and ponds in such a way that the filtration is very imperfect. These imperfectly filtered waters have some of the characteristics of the surface waters from which they are derived, and some of the characteristics of the true ground waters. They also have certain special features of their own in that they contain an unusual amount of free ammonia, a product of decay, and the organism *Crenothrix*, which grows abundantly in such waters. If the surface waters before filtration are objectionable from a health standpoint, owing to the presence of disease germs, the imperfectly filtered waters are subject to the same objections (though possibly to a less degree), and the presence of the intermediate products of decomposition must also be regarded as an unfavorable feature. It is not known that the presence of *Crenothrix* affects the healthfulness of the water, but it is very objectionable for other reasons which will be pointed out subsequently.

With regard to the taste, odor and appearance of ground waters, it may be said that at all public supplies where the water is shown by chemical analysis to be completely purified by filtration, the quality of the water as it comes from the ground is satisfactory. The previous pollution of the water does not give it a disagreeable taste or odor, but, on the contrary, by increasing the mineral contents of the water, makes it if anything more palatable. The only trouble experienced from waters of this class occurs after they have been exposed to the light in open basins or reservoirs, when a bad taste and odor are often produced by the algæ and other organisms which find conditions favorable to their rapid growth in such waters.

The imperfectly filtered waters retain some of the taste and odor of the surface waters from which they are derived and often have a turbid appearance, owing both to the imperfections of the mechanical filtration and to the presence of the *Crenothrix* already mentioned.

For domestic and boiler uses the completely filtered ground waters are satisfactory if not too hard. In the western part of Massachusetts, where there is much limestone, the natural ground waters are frequently too hard to be satisfactory for these purposes; but in other portions of the State, except in the immediate vicinity of the sea, the unpolluted ground waters are but little

harder than the surface waters, and not hard enough to be objectionable for either of the uses named. The excessive hardness of many of the village wells and of some public water supplies is due to the inorganic or mineral contents of sewage and other waste matters washed into the ground from which the supply is derived. These soluble mineral contents of polluted water cannot be removed by even the most complete filtration. It will therefore be seen that any pollution upon the water-shed of a ground water supply not only affects the quality of the water from a health standpoint, but also makes the water less satisfactory for domestic and boiler uses.

Imperfectly filtered waters are not generally objectionable on the score of hardness; but as the organism *Crenothrix* has the peculiar property of separating the dissolved iron from water and incorporating it in its sheath where it exists as iron-rust, such waters are unsatisfactory for use in the laundry because white clothes become much discolored by the rust.

The foregoing statements are not wholly applicable to very deep wells, although, in the few instances in which wells of this character are used for public water supplies in Massachusetts, the quality of the water is about the same as that obtained from the more shallow wells. In other instances the quality of the water obtained from very deep wells has been very unsatisfactory.

It may be thought that the quality of a ground water will vary with the method adopted for its collection: as, for instance, that a driven well will furnish better water than an excavated well or filter-gallery. The examinations of the water supplies of the State do not indicate any noticeable difference in the water collected in these different ways, provided the water is not exposed to the light, and the conditions are not such as to produce imperfect filtration.

Crenothrix is the greatest pest in ground water supplies and, as has been stated, is associated with imperfect filtration. The relation of *Crenothrix* to imperfectly filtered waters has been fully discussed in a report of the Massachusetts State Board of Health upon the Examination of Water Supplies, 1890, pp. 777–782; but the subject is of so much importance when selecting a ground water supply, that the conditions under which *Crenothrix* has been found in abundance will be referred to here. The principal instances are furnished by the water works at Wayland, Arlington, and Whitman. At each of these places the filter-gallery is built near the shore of a reservoir, in material which is not very porous; and at both Wayland and Arlington small branch galleries extend out under the reservoir only a few feet below its bed. In each case the chemical analyses show that the water is imperfectly filtered and contains the products of decay. It may also be mentioned that in each case the unfiltered reservoir water contains a large amount of organic matter.

There are other instances in the State where attempts have been made to obtain filtered water by means of systems of open-jointed pipes laid beneath the bottoms of reservoirs; but the quality of the water obtained has not been good, owing probably to imperfect filtration and *Crenothrix*. Still other instances in which a growth of *Crenothrix* has caused trouble are given on this and the following page.

Crenothrix has appeared in some of the ground water supplies in the State where the filtration is nearly complete, but has not multiplied to such an extent as to cause any serious trouble.

It may be asked how far it is necessary to place a well or filter-gallery from a stream to insure a practically complete filtration of water. There are several instances in the State where the bank intervening between the stream and the well or filter-gallery is not more than twenty or thirty feet in thickness, and yet the water obtained is very completely filtered. These sources, however, are located in very porous ground; and it is probable that, owing to the silting up of the bed of the stream opposite the well or filter-gallery, by far the greater part of the water has to filter by a very circuitous course. It is best, however, where practicable, to place the well or filter-gallery as much as one hundred feet from the stream, and if the material is so impervious that a sufficient quantity cannot be obtained at this distance, it may be said that the conditions are not favorable for obtaining a supply of ground water.

In addition to the ground waters, already discussed, which it has been practicable to group with reference to certain special characteristics, there are others met with under special conditions which present some peculiar features.

Wells driven in the sand in some parts of Provincetown, at the end of Cape Cod, furnish water having a very high color and a strong odor. This may be accounted for by the existence of deposits of organic matter, largely of marine origin, beneath the sand drifts of this region.

In the water supply of the Westborough Insane Hospital, taken from driven wells near Chauncy Pond, the amount of free ammonia in the water has always been extremely high, and after several years' use of the wells, has increased about a half. The organic nitrogen has also increased to more than twice the original amount, and *Crenothrix* and other organic growths are now found in the pipes, making the water unsatisfactory for use in the laundry on account of the rusty stain left upon the clothes.

Wells sunk at Lexington in peat, hard pan and rock, furnish water having considerable color, and some other characteristics of surface water.

There is an instance where water taken from a filter-gallery beneath the bed of an old mill-pond has color and turbidity owing to the presence of *Crenothrix* and *Zoogloea*, is hard, and has an offensive odor. In another instance wells driven in a salt marsh have furnished very hard water. Still another instance may be mentioned in which a driven well near a large swamp has furnished a water which was colorless when drawn, but acquired considerable color on standing for a day, and also had the odor of sulphuretted hydrogen.

These special cases have not been sufficiently investigated to warrant an extended discussion at the present time, but they are mentioned to indicate the necessity, notwithstanding the general good character of ground waters, of having analyses made of water from test wells, and of considering carefully what changes in the character of the water may occur when the currents of water in the ground are changed by continuous pumping.

DISCUSSION.

THE PRESIDENT. The paper is now open for discussion.

MR. FULLER. Mr. President and gentlemen, my experience has been almost entirely with ground water supplies, and so far has been that those waters are very satisfactory. Half a dozen works I have had to do with have obtained their supplies from the ground, and I believe in every case the quantity has been sufficient and the quality has been excellent. Their history has not extended over the dry season which Mr. Stearns has spoken of, the year 1883, and I presume some of them would suffer, and extensions would have to be made to carry them through such a year as that. I think there is one thing that might be said in favor of ground water supplies, that in many places it is the only supply that can be obtained. I think in these half dozen cases I have in mind it would have been impossible to have obtained any supply that would have been satisfactory outside of the ground. I think, possibly, in one or two instances a supply might have been obtained by pumping from some pond, but I am sure the water would not have been so acceptable to the people.

Now, as Mr. Stearns has told us, it is not always possible to determine beforehand just what *amount* of water can be obtained, but yet I think in almost every town there is some point where a ground water supply can be obtained. There is almost always some low portion of the town near some stream, some meadow, from which, by selecting the proper place, finding where the porous material is, and of the largest extent, a good supply can be obtained; and if this water is pumped into a covered reservoir or tank it will certainly make a very desirable supply. The appearance of the water is generally better than the appearance of a surface water, and if the supply is delivered fresh, the people, I think, appreciate the difference between a ground water and a surface water. I know in my own town, Wellesley, occasionally, before we made certain extensions, we had to run a small quantity of brook water into our gallery, and the people were aware of it in a very short time, and we had complaints on all sides that we were pumping brook water, although I have no doubt that the water of the brook would analyze very well indeed, and it was a good clear water, still it had that peaty taste which is common to many surface waters.

I would like to ask Mr. Stearns if he can tell us about what the average hardness of ground water and of surface water is.

MR. STEARNS. I should say, if you get the unpolluted ground waters of eastern Massachusetts, that is, everywhere east of the Connecticut River, and in some portions west of the Connecticut River, that there is very little difference between the hardness of a ground water and of a surface water. Perhaps the ground water is a fourth or a third harder, but either is so soft as to be entirely acceptable. Whereas, you take a great many of the ground water supplies of the State, and as matter of fact they are obtained from districts where they are somewhat hard, and in some cases extremely hard, through the amount of mineral matters of the sewage, which comes to them as I stated in my paper.

MR. FULLER. In the case of Foxboro, the report of the State Board of Health with regard to hardness was that the water we were pumping was only .63 of one part in hardness, which seemed to me to be a very soft water. Isn't that so?

MR. STEARNS. That is an extremely soft water, and the same may be said as to the Mansfield supply, and the same as to recent analyses from wells at Attleboro in that region; and there are numerous instances all over the State of ground waters that have less than a degree of hardness, when they come from an unpopulated region.

MR. FULLER. What is the hardness of the Cochituate and Sudbury River water?

PROF. DROWN. One and a half.

MR. STEARNS. Sudbury and Cochituate both have more residue when they are boiled down than the ground waters that I have mentioned, and that would be the case with nearly any peaty waters.

THE PRESIDENT. I will now call upon Mr. Noyes, who has had experience with ground waters.

MR. NOYES. Mr. President, I have been exceedingly interested in the reading of Mr. Stearns' paper. It is a paper which I have long desired to have presented to the Association, for I know Mr. Stearns in his very extended investigations over the State had a fund of information which would be of great value to us all in the study and determination of the quantities and the qualities of water supplies. I do not know that there is much for me to add, for he has very fully covered the ground as to both surface and ground water supplies. There is one point, however, that possibly he has not touched upon or brought out as fully as it seems to me it might be, and that is the percentage or quantity of ground water available, that comes direct to the supply from bodies of water or streams that may be adjacent to the water supply of any particular place.

I think it has been assumed for some time that the infiltration from a body of water to the ground was very small, and in fact I think it is now pronounced by engineers of considerable experience to be absolutely nothing. And the familiar test that has been made, I think, in some of the suits for water damages to show that there was no infiltration, or no water taken from these bodies of water, was to drive a tube well in the stream, and when the water was observed to rise above the level of the stream and flow out of the pipe, the conclusion was that there was no infiltration. Under this condition of things it does show that there is no infiltration. But when you are drawing upon a ground water you are ordinarily drawing to several feet or to a considerable depth below the level of the stream. And in these cases, from observations which it has been my pleasure to make in the last few years, I am convinced that there is a very considerable percentage of infiltration from the adjoining body of water into the ground, which very largely increases the quantity that is available to that supply.

Notably that came to my attention some years ago in making an extension for the water supply of the Newton Water Works. As may be known to most of you the water supplies for Newton, Brookline, Wellesley, Waltham, Dedham

and Watertown are taken from wells, galleries or driven wells, adjacent to the Charles River, and the Charles River being a river in which the level of the water, at least beyond Dedham, is controlled by a series of dams, it may be looked upon as a series of ponds. The territory adjacent to the river is of glacial formation for quite a distance from the river, and in many cases is made up by sharp moraines of coarse gravel or coarse sand, which is a condition which allows a very large percentage of the rainfall to filter into the well, and offers very favorable conditions for supplies. For the most part the level of the ground water is slightly above that of the normal level of the water in the river, but the level in the river rises and falls with the drawing of the water at the mills, and also by the increased volume flowing through the river, so that there is near the surface on the banks a very considerable area, when you come to take the total area, which is subjected to the wash or the current of the stream, thereby keeping the pores of the earth more or less open and not subject to the silting action that is ordinarily said to exist, or is supposed to exist in streams.

Now, notably in the case of the Newton water supply, having occasion to dig a well for drainage purposes, that is, for drawing the water down so that the work could be prosecuted, we found a stratum of gravel which admitted the water very freely, and so much so that it was at a very much higher temperature than the normal temperature of the water in the ground. In other words, the normal temperature of the spring water was in the neighborhood of 50 to 51 degrees, whereas this was as high as 60 to 67. This was in the summer. And yet the water itself was clear, while the water in the river was of a very decided brownish color. I also found in driving tube wells ranging 30 to 40 feet deep, that they penetrated strata of gravel which brought water, the temperature of which, as it came from the tubes was very much higher than that of the ground water and perfectly clear. And in the recent work on the extension of the water supply in Waltham, where they had occasion in the construction of their large well to draw the water some 24 to 26 feet, on the river side where the water came in, there was an appreciable difference in the temperature from that on the land side. In these two cases, at least, and in a number of others under similar conditions, where there seems to be probable infiltration of water from the adjoining body and where the flow of the stream is considerable, the amount which is available would be very largely increased.

Prof. Drown. I can add very little from my special standpoint to what Mr. Stearns has said with regard to any of the waters as relating to their composition. I will merely say one word with reference to iron in the waters, which is a subject we do not understand very well, and which I must also say has not been as thoroughly investigated as it deserves. All brown waters, swamp waters, contain iron. That is a part of the color. You remove the color, and you also remove the iron from the water, that is, from solution in the water. And if you filter a brown water and thereby make it colorless, you leave the iron behind in the filter. Experiment shows, too, that if you add a decolorizing substance to water, such as we are familiar with, it not only takes the color out but takes the iron out. So far we understand the situation very well. But how does iron get into the water, into colorless water? We know

very little about that as yet. The problem is a very easy one where the water comes from a region in which there is a good deal of iron in the form of sulphites, iron pyrites, and that we are familiar with in iron springs where the water comes to the surface, and there is a deposit of rust, oxide of iron, that is noticed in the course of the stream. But most of the cases we deal with are not of that character, that is, we do not know that there is in the neighborhood any deposit of iron pyrites which is undergoing oxidation. Take the case of Westboro, that Mr. Stearns referred to, we are entirely at a loss to know where the iron comes from, because it is not associated with color. At the bottom of Jamaica Pond, for instance, at the time of year when the water is stagnant at the bottom—and that is very nearly a colorless water, as you know, not a swampy water—there the water, as taken from the bottom, is very nearly colorless when it is brought to the surface, but very quickly becomes brown, reddish brown, from the separation of oxide of iron. Whether that comes from accumulations of iron-holding material in the bottom of the pond, whether it comes from the organisms which all contain iron more or less, which sink to the bottom, there decay and give up their iron to the water, we do not know certainly. But this seems to be not an unusual occurrence, that waters taken from the neighborhood of swamps, or in the midst of the swamp itself, will give colorless water which contains a good deal of iron.

I do not know that in most cases *that* has any reference to the healthfulness or the palatableness of the water, although, of course, if the water contains an appreciable amount it will give the ink taste to the water, and then of course it is not fit for general drinking. But the trouble comes when we use the water for washing. The iron will separate sometimes with the growth of *Crenothrix*, sometimes without it, but in any case, whether the presence of *Crenothrix* is concerned with it or not, it will make the water rust and unfit for laundry purposes. As I say, I can add very little of information about that, as to how iron gets into solution in colorless waters, which will subsequently separate out when those waters are exposed to the air, because as we draw these waters from the ground they are ordinarily free from air, and the iron separates only when they are exposed to the oxygen of the air. As I say, it seems to me is a subject well worthy of investigation—the character of water from the neighborhood of swamps which supply an iron-holding water which rusts or stains. I hope at some subsequent time to be able to add some information of a positive character on this subject.

THE PRESIDENT. The city of Malden has ordinarily had a very limited supply of water even in the most favorable seasons. We would like to hear from Mr. Allis.

MR. ALLIS. I can't say much about it, because there are three towns drawing from Spot Pond. In our own case we draw a portion of our supply from the pond, having two systems, as I explained here some meetings ago, high and low. Our low system depends upon Spot Pond water, and our high system upon our wells, which have been alluded to already. As has been stated in Mr. Stearns' paper we did at one time pump at the rate of seven hundred and some odd thousand gallons a day for nearly every day of the year.

Since that time the condition of things has been changed, and we are pump-

ing now somewhere about 500,000 to 600,000 gallons daily from the wells, and confining that amount to our high supply. We are pumping from the pond somewhere about the same amount. Therefore the whole amount drawn from Spot Pond, when you take the three towns, Melrose taking perhaps fully as much as we do, is rather excessive in view of the paper read by Mr. Stearns.

In regard to the dryness of the season, we know that Spot Pond is very low. In the year 1883, when it was so very low, the pond reached, if I remember right, 83 or 84 inches below high water mark, and the draft at that time was much less than now. We have now reached the point today of 79⅝ inches below high water. The line on the chart has been running down at a certain angle for four months, if I remember right, 10 or 12 inches a month. Now, having drawn on our wells only for that limited amount, we do not anticipate that we have exhausted them. We have our water table drawn down very slightly; our vacuum holding at 15 to 16 feet. During the months of June and July, when the demand was excessive, we pumped some days a very much larger amount, I think as high as a million gallons a day, from the wells, and about 700,000 or 800,000 gallons from the pond; and we found it quite difficult at certain hours, while the hose was all running, to keep our people on the hills supplied at all. When we put a million draft on the wells our vacuum went down to 23 feet, and we practically got no water. I think we could draw quite a little amount more out of the wells than we are now drawing, however.

There is a question I would like to ask Mr. Stearns with regard to the hardness of the water. I have found within the last few months, our analyses from the State Board of Health showing an increased hardness, and the water from the wells has now reached over 10. I have forgotten what the hardness of Spot Pond water is, but perhaps he can inform us; I think it is less than half of that. I would like to ask Mr. Stearns if he thinks the hardness is due to the infiltration of sewage or the character of the surrounding rocks. We have no limestone in that vicinity, and our rock system is, of course, nothing but slate on the bottom and the common quartzite of the ridge behind it.

One other question I would like to ask, and that is with regard to Spot Pond. Allowing that the three towns are taking from that pond 2,000,000 gallons to-day, are we largely overdrawing under the present condition of things? Our water-shed is about 1100 acres.

Mr. Stearns. The question with regard to the hardness of the well water is a little difficult to answer, perhaps, on account of the fact that those wells go down considerably below the level of the sea, and the ground there is only about five feet above high water mark, although at a distance of two or three miles from the sea. We haven't had enough samples from those wells to know just what goes through the ground. However, I think it is extremely probable that the greater hardness is due to the fact that there is less water falling to dilute the sewage, so the sewage is a little more dense as it goes into the ground, and filters towards the well. I may say at the same time it is extremely well purified when it gets there.

With regard to the other question, if the water-shed is 1100 acres, including the pond—I know that is the statement given in the reports; I had reason to think it was somewhat larger, but still I only know from sources that are not

entirely trustworthy—if the water-shed is only 1100 acres, including the pond, and the pond has an area, we will say, on the average—it decreases as it is drawn down—of 200 acres, bringing the area of the land surface down to 900 acres, or 1000 acres, say about a mile and a half, it is very obvious that when a water-shed only furnishes on an average for a long series of years a million gallons a day to the square mile, that a mile and a half would only furnish a million and a half of gallons a day, and consequently if you draw two millions of gallons a day from that source it must go down, unless the rainfall is 33 per cent. above the average. Now the question as to whether it will go down and stay down, if they draw at that rate, depends upon whether the rainfall remains above the average, or goes down to the average, or goes below the average.

MR. NOYES. I assume, Mr. Allis, you are only draughting this amount of water during the day time, eleven or twelve hours?

MR. ALLIS. That is all.

MR. NOYES. The other thirteen or twelve hours your pumps are still?

MR. ALLIS. Yes.

MR. NOYES. Can you tell me to what point the water in your wells recovers before starting up the next morning, or if the elevation of the water each subsequent morning varies any?

MR. ALLIS. It comes up to its original level.

MR. NOYES. In all cases. And have you made any observations to ascertain in what way it may affect wells in outlying sections; or, in other words, have you noticed to see in what way it may affect the level of the water table?

MR. ALLIS. I have not noticed anything of that kind.

MR. TILDEN. One of the first engineering experiments I was connected with was to ascertain the slope of the ground water when pumping from driven wells, and I resorted to the method pursued by Mr. Houdey about ten years ago at Malden. It occurred to me whether that did not offer some suggestions in the way of ascertaining with the least possible expense whether water could be obtained from the ground from a given area. I think it was used in the case of Malden, and at some other places it has been conducted a good deal by guess work. It occurred to me whether it was not possible to ascertain the amount of water which could be obtained from a given area, by means of a small plant, consisting of a portable boiler and steam pump, and using a two-inch test well. Now, taking as an example the area above Malden, in the vicinity of the Fells Station, at the point that we pumped there, down as far as we drove the wells, about 30 feet, the soil was an open gravelly soil, and should contain about 35 per cent. of water. Now if that whole flat area is supposed from surface indications to be a natural underground reservoir, it could be proved by transferring this temporary pumping plant from one point to another, and ascertaining the area from which you draw the supply of water. Now, to determine whether the ground is porous enough to contain 35 per cent. of water, in other words to form a natural underground reservoir to the extent of 35 per cent. of its area, this can be determined by means of the test well with the small wells ranging out from it, which need be only, for in-

stance, as we used there, three-quarter inch gas pipe. Now, in the course of pumping, the water will be lowered very rapidly in the immediate vicinity of the well, as shown by the test wells, and if the ground contains 35 per cent. of water it will be impossible, I think, with a pump drawing at the utmost capacity of a two-inch well to affect the general slope to a very considerable distance back from the well; and then upon stopping the pump the water should resume its original level. Now, if we put down the test well at a considerable distance away from the center of this area, we would ascertain that the ground was not so porous, and that we were nearing the boundaries of our reservoir. In other words, the whole purpose of this series of experiments would be to ascertain the limits of this underground reservoir, which is not visible from the surface and would not be appreciable by means of boring and testing the soil.

The plant is very cheap, consisting of a portable boiler and a small pump to pump from a two-inch well, and having ascertained the limits of your underground reservoir it seems to me that you could then determine whether its size and the area which it drains would be sufficient to depend upon for a source of supply. I would like to ask Mr. Stearns whether there is any data whatever by which you could ascertain by pumping, that is, by the character of the slope and the distance from which you draw from the soil for a given amount of water, and the rapidity with which it recovers after pumping, whether you were pumping in a soil or in a gravel which would contain this 35 per cent. of water; in other words, whether you could accurately define the limits of the area of this underground reservoir? Having obtained this area and its water-shed, then you could safely put up your larger plant. without putting up your big plant in the first place by guess.

MR. STEARNS. I don't know as I fully comprehend the question. One great difficulty in any test to ascertain the storage is that there may be at the time a great deal of water going into the ground. I think this was the case at the time of the Malden tests. There is no question about the porosity of the soil. I suppose almost any of our soils will hold 35 per cent. of water. The only trouble is they won't all let it out.

MR. TILDEN. I mean whether you could tell from this test if it would let it out, and ascertain the area of your underground reservoir.

MR. STEARNS. I should hardly think you could. It seems to me you can judge better whether it will let it out by an examination of the soil in different places, by means of test wells, by what you actually encounter. You can use your judgment upon the matter.

MR. NOYES. I might say in answer to Mr. Tilden's question that that is the very first thing that is ordinarily done, and in fact a great many times you can by testing the sample make a close proximation of what the soil will yield, from your test well. Another way is to sink four wells and pump from the one in the middle and see how much that one can lower the water in the other three wells adjacent to it and how quick they will recover. But that would only give you only the character of the soil in the immediate vicinity, the amount that you would ordinarily pump from a two-inch well not indicating the character of a very considerable territory. This summer in work I have been en-

gaged in, putting in sewers, I have been into a territory where the gravel was very coarse, very free-flowing, so a six-inch centrifugal pump was kept pumping at its full capacity for several weeks day and night, but could not produce any appreciable drop in the level of the water for something like a month. Then it dropped very rapidly, in fact the basin was pumped completely dry, and the water did not recover its level for a long time. A test made as you suggest gives an idea of the soil in the immediate vicinity, but not of any considerable territory.

MR. TILDEN. The plant I propose was so comparatively inexpensive, and so easily put down and transferred from point to point, that you could thus ascertain whether the character of the soil was such as practically to constitute an underground reservoir. You take the ground at Hyde Park, the gravel is so coarse and open that the whole valley there is practically one immense reservoir. Now, if you had any idea that it was limited, the extent of it could be easily determined in this way. It seems to me you must have a very large underground reservoir before you can depend upon it for a source of supply, and in order to determine its limits I don't see why you can't proceed in that way, in the first place; by moving this plant from point to point and ascertaining, better than you can from test wells or better than you can from borings, by the character of the slope given in pumping a certain amount of water.

MR. NOYES. That is practically the test that I should ordinarily make, but I think it would be after a study.

MR. ALLIS. It has been said in Malden by a prominent physician that the water from the wells is very unhealthy on account of hardness, and I would like to have Mr. Stearns tell me whether he thinks that is the fact or not?

MR. STEARNS. I don't know much about the healthfulness of the water. It undoubtedly contains a large amount of mineral matter, but I have not known that such waters were injurious, so far as my experience goes. Whether, its source being to some extent sewage, even though the chemical analysis shows it to be thoroughly purified, has any bad effect, may be a matter open to question.

PROF. DROWN. With reference to the question asked by Mr. Allis, I will say some investigations were made in England many years ago on that particular point, whether the hard waters of England were more unhealthy, or fully as healthy or more healthy than the soft waters, and the results of statistics showed that there was no higher death rate in the regions supplied by hard water than in those supplied by soft water. And in England where they have hard water they have it very, very hard, much harder than it is in Malden. Of course there are so many things enter into the question of the death rate in any locality that it is hard to eliminate all the others and confine investigation to one point. I think it may be safely said, however, that the hard waters, other things being equal, are not more unhealthy than the soft waters. Certainly the larger part of the waters in our western states are of a degree of hardness of which we have no conception in this region.

NOTE.—The following discussion by Samuel B. Leach was read by the Secretary:

Mr. President—The Tarrytown Water Works were designed and the construction of them superintended by me in 1889. The supply is taken from an open well 15 feet in diameter and 42 feet deep, and drains a water-shed or catchment basin of one and one-quarter square miles of area. My original plan was to sink two wells 30 feet diameter each, but before my engagement for the work the Board of Water Commissioners of the village had been advised by three prominent engineers at different periods that a sufficient supply for the village could not be obtained from that locality, and on account of that advice the Commissioners wished me to make the first well only 15 feet diameter, although I advised a larger one. Another well is now being sunk and is to be connected with the first one by a siphon pipe. The basin in which the well is sunk is in the form of a horse-shoe with the well at the narrow outlet, to the east the Hudson river is distant one and one-half miles and 240 feet below the surface of ground at the well and pumping station, thus requiring the water from the well to be raised but 75 feet to the main distributing reservoir to give 125 pounds pressure in the mains in the lower portion of the village, while for the high service it is raised 200 feet.

The strata found in sinking the well was for the first 3 feet vegetable mould, then 12 to 15 feet of various grades and qualities of sand, and from that down gradually working into gravel and finally boulders.

The amount pumped was all the village required, while it is my judgment that had it been demanded and with a larger well 200,000 gallons daily would have been obtained during the excessive drouth, and an average of 400,000 daily for the year.

Number of gallons of water pumped for the past six months is as follows:

1891.		Daily Average.	Per Capita.
May	3,300,525	106,468	28
June	5,184,956	172,831	45.5
July	3,820,488	123,241	32.5
August	3,804,062	122,711	32
September	3,790,768	126,358	33
October	3,243,890	104,641	27.5

The population is about 3800, and there is no manufacturing.

All water sold is *metered*, with no exceptions.

During the months of May and October there was no street sprinkling.

THE PRESIDENT. There is one question I should like to ask Mr. Stearns, and that is whether water will deteriorate if left exposed in a reservoir a great length of time.

MR. STEARNS. I think it depends on the quality of the water when it goes in there. As a rule I do not think surface waters do deteriorate. We have had some cases where water has been examined after being in the reservoir a very long time without any being drawn out or let in, and I should say it was as good, and in some cases better than when it was put in. Ground waters, as I have already stated a good many times, are so very good when they go in that they can hardly improve, and as a rule they generally deteriorate. But I think the deterioration of ground waters as they go into reservoirs is more likely to occur in the first two or three weeks and reach the worst, perhaps, within a month, and then that they would by long storage tend to improve.

MR. WHITNEY. I would like to ask what becomes of the 50 per cent. of the rain fall which does not seem to be available as a water supply.

MR. STEARNS. I suppose the whole 50 per cent. is evaporated, in some water sheds, and, perhaps, 50 per cent. is a very good average figure. On the Sudbury 49½ per cent. is collected, and I think very little goes into the ground past the lower dam. In other water-sheds, I will take the Cochituate for one, there is 43 per cent. collected, but it is not impossible that several per cent. disappear by filtration through the ground into the lower territory, because Lake Cochituate is only separated by a gravel ridge from lower territory on one side for a portion of the distance. That is, sometimes we have only the loss by evaporation, which may be 50 per cent., and sometimes we have in addition a loss by filtration to lower levels.

MR. RICHARDS. For how many years is 50 per cent the average?

MR. STEARNS. The 50 per cent. I gave upon the Sudbury River, and I chose those records over all others because there is so little filtration, is the result of sixteen years' observations. The table I gave for the Croton watershed would seem to indicate just about the same thing, because the amount of water flowing is the same, and the rainfall is just about the same.

MR. RICHARDS. I think that great emphasis should be put on the danger of using figures showing the *average* amount collected, for it is not the average but the minimum that we must provide for. Mr. Stearns' paper also shows clearly that it is not the quantity of rainfall but its distribution which is the governing factor in ascertaining the quantity of water that may be collected from a given area. The factor of leakage may also be a large one. At the storage reservoir at New London, Conn., in 1883, we were able to retain but 17 per cent. of the rainfall, while in 1884, with an increase of 20 per cent. in the rainfall, we retained 33 per cent. of it. In other words, with 20 per cent. more rainfall we saved more than double the quantity of water, showing the great influence which a favorable distribution of rainfall has. The low percentage saved is partly accounted for by leakage, due to the peculiar forma-

tion at the lower end of the reservoir, the dam at that point being flanked on either side by sand hills, through which the water percolates from the reservoir.

Mr. Stearns. I am very glad Mr. Richards has brought up this question, because there is danger in speaking of averages that the average figures should be used, when they should not be used at all in water supply examinations. In 1880, when there was only 31 inches of rainfall on the Sudbury river, there was only 31 per cent. of the water collected leaving 69 per cent. for the evaporation. In 1883 there was 34 per cent. collected, leaving 66 per cent. for evaporation. That is, with a low rainfall you may have nearly as much evaporation as with a higher one, not as much, but nearly as much, and consequently the amount you have left after evaporation, is reduced very much indeed. While with a high rainfall, such as we had in 1889, there was 58 per cent. of the water collected and only 42 per cent. evaporated. It varies very much with the amount of rainfall.

Mr. Chace. There has been so much said of late with regard to the dryness of the past season that I had the curiosity a few days ago to compare the rainfall in Taunton for the year 1890 and for the present year, taking our financial year from the 1st of December to the 1st of December; and I found that from December 1st, 1889, to December 1st, 1890, it was 52.82 inches, and from December 1st, 1890, to December 1st, 1891, it was 51.08—that is only .74 inches less for the whole year than for the previous year. But on looking a little further I found that from the 1st of March to the 1st of November last year the amount of rainfall was 13.89 inches more than for the present year, that is, 32 per cent. less in 1891 than in 1890; and whereas our filter-basin at this season of the year is generally full up to the coping stones, we have not had it half full during the whole year, even with the aid of the river.

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NOTES ON SOME CASES OF DRINKING WATER AND DISEASE.

By William P. Mason.

[*Read at the stated meeting of the Chemical Section, of the Franklin Institute, held May* 19, 1891.]

Drinking water and disease, upon which I am expected to speak tonight, is a question of such exceeding breadth, that so considerable a title certainly outweighs the small amount of matter capable of being placed within the compass of a short paper. I therefore beg to present only some few facts which have come within my own experience, and certain other matter bearing directly thereupon.

In that most excellent treatise upon "Water Supplies and Inland Waters," recently issued by the Massachusetts State Board of Health, waters are classified into "normal" and "polluted," the former being such as are free from addition, directly or indirectly, of either sewage or industrial waste.

The relation of "normal" waters as a class, to sanitary science, constitutes a subject by itself, and one by no means completely understood, as is instanced by the doubt we entertain of the effect of fresh water algæ upon our city supplies. However objectionable such growths may be from an æsthetic point of view, owing to the disagreeable odors generated, we must nevertheless confess to much ignorance as to their pathogenic importance. It has been my fortune to meet with but few cases of illness traceable to normal waters, and in all such instances the patients suffered from a mild and transient form of diarrhœa, caused by water from a low-lying small lake or pond, surrounded by low wooded banks. Of course, as in the experience of other water analysts, the commonly reported cases of algæ have been met with, but no material has so far been secured whereby disease could be traced to their presence. We will all look with interest to the results of the investigation now being undertaken by the American Water Works Association, and we hope for further light upon this point.

As concerning the second division referred to above, namely, polluted waters, permit me, for the moment, to make a further subdivision, and consider the admission of sewage from pathological sources, as distinct from that derived from healthy persons. I ask for the distinction because without it, it would often be hard to account for the long-continued immunity from disease, enjoyed by people who habitually make use of waters which are unquestionably grossly polluted.

How often do the cases of contaminated city wells illustrate this point, and how frequently is the chemist met by this refuting "test of experience," when he knows not only from the results of his own analysis, but from personal inspection of the vaults in the neighborhood, that such wells drain sources of

outrageous filth. In view of the over-taxed purifying powers of the intervening soil, there is but one way out of the dilemma, and that is that sewage from pathologic sources has as yet not chanced to reach these wells, or else that such persons as swallow specific germs do not, at the time, furnish suitable ground to grow the seed which disease has planted.

You will remember that Emmerich made very light of the objections raised against ingestion of sewage material, and even went so far as to personally consume no inconsiderable quantity of it daily, and induced some students of his to do likewise. In contrast with his physiological results, permit me to relate a somewhat interesting case with which I was connected.

Rain-water, from a cistern of the filtering type, situated upon carefully managed property, had been in use for some years. Suddenly, with little warning, the entire household, one person excepted, were taken ill. The symptoms varied from intense nausea to great, if not dangerous prostration. The one person who escaped illness was the only one who did not use the water. Among those attacked were several children.

Upon investigation, both cistern lining and private sewer were found defective, and permitting of more or less direct communication. Up to the time of the outbreak none of the household had suffered from diarrhœa or kindred troubles, nor could I obtain any history of recent disease of any kind. The children attacked were on a short visit only. The point to be emphasized in this case is that the sewage which caused the trouble was "normal." Although I secured an analysis of the water at the time illness was produced, it is to be regretted that no previous analyses were on record, which might have established some relation between the figures of the analysis and the "poisoning point" of the water.

The serious evils lurking in water containing sewage derived from sources of disease, are too well-known to need enlarging upon here, and the dangers to be dreaded from the improper disposal of city drainage, is one of the widely-talked-of topics of the day.

Much has been said and written upon the ability of sewage-laden streams to purify themselves, and authorities of great weight are to be found on either side. Some time since a series of analyses were undertaken, as you will remember, by Dr. Long, of Chicago, upon the dilute sewage contained in the Illinois and Michigan Canal. It is to be noted that this canal receives its supply of water (or rather dilute sewage) at Bridgeport, where the pumps deliver to it the filthy water of the Chicago River, contaminated with a great portion of the sewage of Chicago. From Bridgeport the water "flows along the level to Lockport, twenty-nine miles below, requiring about a day for its passage." It receives no dilution on the way and is frequently agitated by passing boats. "After passing Lockport the water descends to Joliet through four locks, and falls over a dam seven feet in height to point of collection. There is a fall of 58.2 feet in a distance of four miles, and no dilution takes places on the way." The experiments with this canal water have been both numerous and thorough, and judging from the mean results there is good ground for the statement that very considerable self-purification takes place during the flow of thirty-three miles.

I have long been of the opinion, however, that what may be very true for dilute sewage, does not hold good as we approach the limit of potable water.

In other words, so far as purification of a water by the natural processes of oxidation is concerned, I believe that the rate of such purification varies directly as the amount of sewage contamination. Given a stream with a certain amount of pollution, the per cent. of such pollution which must disappear per mile of flow, will continually decrease as the stream flows on. To return to Dr. Long's figures. The analyses as given by him are as follows, in parts per million:

	Free Am.	Albu. Am.	Oxygen Consumed.
At Bridgeport:			
June 26	2.6	0.64	12.0
July 3	2.7	0.52	6.8
17	25.0	1.50	22.4
24	5.5	0 37	12.6
31	23.0	1.76	23.2
Aug. 7	26.0	1.50	16.8
14	29.0	1.64	32.0
21	27.2	1.50	28.0
28	29.2	1.90	35.2
At Lockport:			
June 26	2.8	0.56	11.36
July 3	2.4	0.42	7.20
17	10.2	0.72	12.80
24	9.2	0.47	14.80
31	11.0	0.72	10.70
Aug. 7	12.0	0.48	9.60
14	15.2	0.88	9.76
21	15.0	0.84	10.80
28	13.0	0.88	12.40
At Joliet:			
June 26	1.7	0.46	7.36
July 3	1.8	0.46	9.76
17	13.0	0.44	14.50
31	9.2	0.44	5.68
Aug. 7	7.5	0.42	5.84
14	9.8	0.46	5.76
21	9.0	0.11	0.52
28	8.0	0.32	6.80

Plating these in graphic form they assume the shape shown on the accompanying charts.* The change in lake level at various dates, together with other disturbing influences, caused comparatively clean water to reach the pumps at times, and we, therefore, are furnished with data governing the pur-

*Charts omitted.

ification of several variously contaminated waters, while flowing under constant conditions.

It will be noticed that the rate of purification per mile for the more grossly contaminated samples, is much greater than that for those comparatively pure. Thus, during the flow from Bridgeport to Lockport, the sample of July 3d loses 11.2 per cent. of its free ammonia and 19.3 per cent of its albuminoid ammonia, while the sample of August 28th loses 55.5 per cent. free ammonia and 53.7 per cent. albuminoid ammonia while flowing the same distance.

Even the best of these waters of the Illinois and Michigan Canal is very far from being potable, and we may consequently look for still further reduction in the purification rate as we near the potable limit. My experience with the waters of large streams contaminated with city sewage, for instance, the Hudson River, is that self-purification is exceedingly slow. Having been employed by the Board of Health to examine into the quality of the Hudson River water opposite Albany (which water, taken directly from the side of the wharf, constitutes the present city supply), I made a very thorough examination of that section of the river. Permit me to digress here for a moment to state that it is my conviction that analyses of water from any one spot in a large stream, are valueless for the purpose of determining the continued presence of up-stream contamination. The dilution is commonly much too great to permit the sewage revealing itself. The Albany case is one in point. In order to determine whether Troy sewage, entering six miles above, was felt at the Albany intake, the river water was first sampled above Troy and then below the Troy sewer outfalls, where no one would hesitate to say that contamination was serious. A difference was noted between the two results which was undoubtedly caused by the influx of the Troy and Mohawk River sewage.

Upon continuing the collection of samples, every mile there were obtained analytical results which showed that the difference between the waters above and below Troy was largely maintained when Albany was reached. On the strength of the maintenance of this difference, rather than upon the results of any separate analysis, I pronounced against the Albany water supply as being contaminated with sewage from up-river sources. Directly relating to what has been referred to, let me finally ask your attention to a few facts of recent history, bearing upon the late outbreak of typhoid fever in Albany and vicinity.

By a glance at the accompanying chart,* the locations will be observed of the several cities and towns situated at and near the junction of the Mohawk and Hudson Rivers. Every one of these centres of population drains into the river on whose banks it is situated, and each of them takes the greater portion of its water supply directly from such river by means of pumps. Mark this difference, however, Waterford, Lansingburgh and Troy are supplied with Hudson River water above the junction with the Mohawk, and the village of Green Island obtains its water from wells driven into its sandy soil. It is therefore supplied with filtered Hudson River water, while all the others use Mohawk or Mohawk-Hudson water.

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*Chart omitted.

The several intakes are indicated on the chart by squares. Under date of April 11, 1891, the Health Officer of Schenectady writes me: "The marked increase in typhoid fever began in July, 1890, and has just let up. We have had about 300 cases. Doctors have not been particular in reporting them, and we have had so many cases of anomalous fevers, that diagnosis is questionable. Seventy deaths have been reported." Permit me to say that it has not been the rule during this epidemic, for physicians to do their whole duty in reporting cases. I know of one instance in which only two or three cases were reported out of twenty-five. Schenectady is a very old town (of 20,000 inhabitants), and its sewerage system is doubtless none of the best, but its drainage eventually reaches the Mohawk and is carried onward with the current.

The following information was obtained from Dr. Leo, Health Officer of Cohoes, and from Dr. Peltier, his predecessor. Population of Cohoes is 22,000.

The epidemic of typhoid began in Cohoes about the end of October, 1890, and ceased about the middle of the following March. Altogether there were about 1,000 cases. The cases were mild in character, resulting in very few deaths. Cohoes takes its entire water supply from the Mohawk and returns its sewage into the same river. Boiling of water for drinking purposes was recommended, and no typhoid developed among families who followed the recommendation, except in those instances where members of such families drank unboiled water while at work away from home. A portion of the city is owned by the great Harmony Knitting Mills, and is built up with tenements for their employes, of which there are many hundreds. These tenements are kept in excellent repair and the plumbing is the best in the city, but extends to kitchen sinks and drains only. No water-closets are employed, as each house is furnished with privy vault in back yard. Typhoid was especially bad in this quarter. The Cohoes Health Officer has professional occasion to visit in Waterford (population 5,400) and in Lansingburgh (population 10,000), which towns are connected with Cohoes by bridges. He reports that hardly a case existed in either of those towns, and it is to be noted that they draw water from the upper Hudson above the Mohawk junction.

West Troy is situated on the Hudson and sewers therein, but by aid of the chart it will be noticed that its water supply comes from the Mohawk some distance above Cohoes. Its population is 13,000. The following information was obtained from Dr. McNaughton, health officer:

Epidemic of typhoid began the last of November. At meeting of Health Board, about December 15th, fifty cases were reported. Of these, forty-two had used Mohawk water, the remainder well water. On December 20th, the Mohawk supply was shut off and arrangements made with the town of Green Island (which village, by the way, had no fever) to use a portion of its supply of filtered Hudson water. One week thereafter the weekly report of cases showed fifteen, and the second week thereafter but one case was reported. The Green Island supply was used one month. Upon returning to the Mohawk supply in the middle of January, a slight increase in typhoid was observed. Total number of cases exceeded 100. The fever, as in other places, was very mild, resulting in ten deaths. Troy is situated directly opposite

West Troy. Its population is 60,000. Its water supply comes partly from lakes back in the hills, partly from the Hudson above the Mohawk junction.

There have been very few cases of typhoid in Troy during the past year, and of those few a large percentage were imported from Schenectady and West Troy.

Troy dumps 8,000,000 gallons of sewage into the Hudson daily.

Six miles below Troy is the city of Albany; population, 100,000. Albany takes it water through an intake in the side of the wharf, directly in front of the city. Not only does sewage from the upper Hudson and Mohawk flow towards it, but during flood tide and south wind, the return of its own sewage from the sewer outfalls below has been proven by the floating of buoys.

The typhoid epidemic began in Albany the last of December, 1890. The disease was very mild in character, resulting in sixty-two deaths during the months of January, February and March, 1891. The total number of typhoid cases reported during the same period is 411, but this figure I have reason to know is absolutely unreliable. Albany experienced a very serious epidemic during the past winter, and the alarm was widespread, of that there can be no question. A small portion of the city receives its water supply from an inland gravity source. Typhoid was not nearly so plenty in that section, only eighteen cases being reported to the end of March.

An attempt has been made to fix the Albany epidemic upon the bad sanitary conditions of the house drains, whereby sewer air was admitted into the dwellings. In one section visited, sixty-five houses out of seventy-five possessed drains which leaked sewer air, and at the Albany Penitentiary, where the drainage system is perfect and where the inmates drink unpurified river water, there occurred no case of typhoid.

Faulty drainage, permitting the inhalation of sewer air, doubtless would induce a condition of the system favorable to the propagation of the typhoid germ should it be introduced, but it must be remembered that Troy has sanitary surroundings and appliances fully as undesirable as Albany, yet no epidemic occurred there.

Possibly the excellent sanitation at the penitentiary maintained the inmates in a condition of health such as to resist the planting of the disease.

Finally, as I am informed by Dr. Craig, of Albany, at Van Wie's Point, four miles below Albany, the laborers employed in cutting ice for the great ice-houses, had typhoid fever break out among them during January. They used river water for drinking purposes.

To conclude, typhoid germs have been carefully looked for in the water and have not been found. But in view of the relative volumes of a city water supply and a sample for bacteriological examination, such a result does not appear surprising. There are those who hold that this outbreak of typhoid fever is to be explained in some other way than by attributing it to a contaminated water supply, but when we bear in mind that, out of this group of closely situated cities and towns, all of those which used the Mohawk-Hudson water contracted the fever, and that all those which did not use such water escaped, there is much food for thought.

Rensselaer Polytechnic Institute,
Troy, N. Y., May 18, 1891.

OBITUARY.

SAMUEL B. LEACH—Civil Engineer, Tarrytown, N. Y., died at Liberty, N. Y., January 28th, 1892, aged 67 years. Joined this Association, December 11th, 1889.

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S. P. Jones 20

93,000.

A MARVELOUS TEST.

NEW YORK, June 8, 1891.

HON. ROBERT E. SMITH, Commissioner of Public Works, Providence, R. I.

DEAR SIR:—We have had the pleasure of furnishing your Department during the past ten years about 5,500 Crown Meters. In the last shipment of 50 ½ Crown Meters furnished you, we sent five of our "A" style of Crown Meter. We write to ask you if your Department has tested any of that lot of meters, and, if so, will you kindly send us a copy of such test?

Yours very truly,
JOHN C. KELLEY, President.

[COPY.] DEPARTMENT OF PUBLIC WORKS.

ROBERT E. SMITH, Commissioner. COMMISSIONER'S OFFICE, CITY HALL,
JOHN C. KELLEY, Esq., President National Meter Co., Providence, R. I., June 11, 1891.
252 Broadway, New York.

DEAR SIR:—Your request of the 8th inst., for a copy of the test for accuracy of a ⅝ Crown Meter, "A" pattern, is received. Inclosed find copy of the test of meter No. 84,169.

Yours respectfully,
ROBERT E. SMITH, Commissioner.
By W. F. SLADE, Secretary.

Test for Accuracy 1-2 inch Crown Meter No. 84,169, "A" Pattern, March 31 and April 2 and 3, 1891.

WATER PRESSURE.	FAHR.	TIME.			METER	TANK.	OUTLET. Brown & Sharpe Disk.	PER CENT.
		Hours.	Minutes.	Seconds.				
70 lbs.	70 Deg.	..	4	..	10 feet.	623 lbs.	$\frac{1}{2}$ inch.	.0
70 "	70 "	..	7	23	10 "	617 "	$\frac{1}{4}$ "	0.8
70 "	70 "	..	30	5	10 "	618 "	$\frac{1}{8}$ "	0.9
70 "	70 "	..	22	20	2 "	124 "	$\frac{1}{16}$ "	0.4
70 "	70 "	1	13	20	2 "	127 "	$\frac{1}{32}$ "	1.9
70 "	70 "	2	43	..	2 "	126 "	$\frac{1}{50}$ "	1.2
70 "	70 "	3	23	..	1 "	64 "	$\frac{1}{75}$ "	2.7
70 "	70 "	5	50	.	1 "	64½ "	$\frac{1}{100}$ "	3.5

WHAT DOES THIS TEST SIGNIFY?

One Cubic Foot of Water on 1-2 inch Stream was Registered in 24 Seconds.
" " " " $\frac{1}{100}$ inch " " 21,000 "

The disks used were made by Brown & Sharpe Manufacturing Company.

NATIONAL METER COMPANY,

MANUFACTURERS OF

Crown, Empire, Gem and Nash Water Meters,

252 BROADWAY,

BOSTON, 159 Franklin Street. NEW YORK.

93,000

WATER METERS MADE AND SOLD.

DECEMBER, 1891. s.d m.j.

PEET VALVE CO.,

MANUFACTURERS OF THE

Genuine Double Gate Peet Valves,

FOR STEAM, WATER, GAS, Etc.

Special Valves for all purposes Made to Order.

Peet Valve Co.,

163 Albany St.,

Boston, Mass.

a.d.m.j.

THE POPULAR AND DURABLE

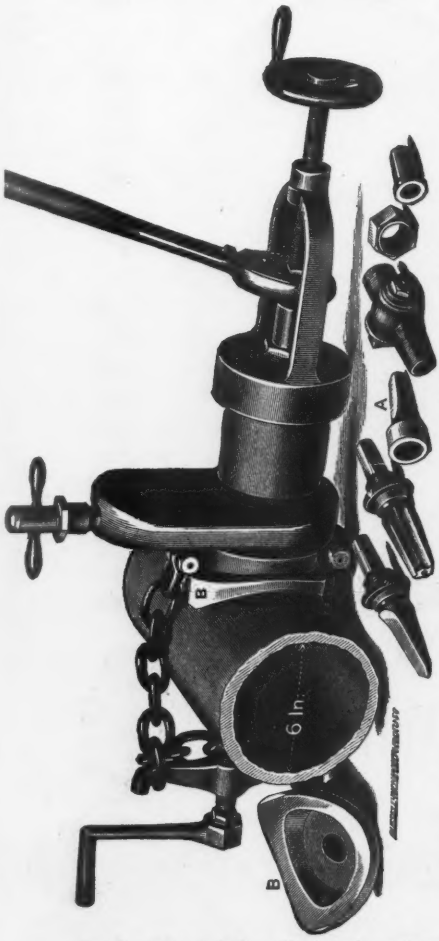
E. R. JONES'

TAPPING MACHINE

Will insert stops 1-2 to 1 1-2 inch into 4 to 24 inch mains without shutting the water off.

No other Equals it in Efficiency or Durability.

—AND—



The following are among the cities and towns using this Tapping Machine: Auburn, Bangor, Bar Harbor, Brewer, and Old Town, Me.; Dover, Littleton, Nashua, N. H.; Morrisville, St. Johnsbury, Waterbury, Vt.; Boston, Brookline, Cambridge, Charleston, Clinton, Everett, Fall River, Fitchburg, Holyoke Haverhill, Lowell, Lawrence, Leominster, Marlboro', Maynard, Milford, Newton, New Bedford, North Adams, North Bridgewater, North Attleborough, Norwood, Springfield, Taunton, Waltham, Westfield, and Worcester, Mass.; Pawtucket, Providence, Westerly, R. I.; Norwich, Conn.; Hornellsville, Hudson, Mt. Morris, Norwich, New Berlin, New Rochelle, Oneida, Oswego, Rochester, Troy, and Yonkers, N.Y.; College Point, Flushing, and Long Island City, L. I.; Atlantic City, Bayonne, and Jersey City, N. J.; Norristown, Penna. Steel Co., Sayre, Pa.; Wilmington, Del.; Cincinnati, Columbus, Dayton, Ironton, Martin's Ferry, Portsmouth, Sandusky, and Toledo, Ohio; Belleview, Covington, Henderson, Maysville, and Newport, Ky.; Evansville, Ind.; Jackson, Mich.; Milwaukee, Wis.; St. Joseph and Sedalia, Mo.; Jacksonville, New Orleans, La.; Salt Lake City, Utah; Sacramento, Cal.; Fredericton, N. B.; Barbadoes, W. I., and many others.

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Carr's Patent Automatic Supplementary or Double Valve Hydrant,

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Iron Founders,

and Machinists.

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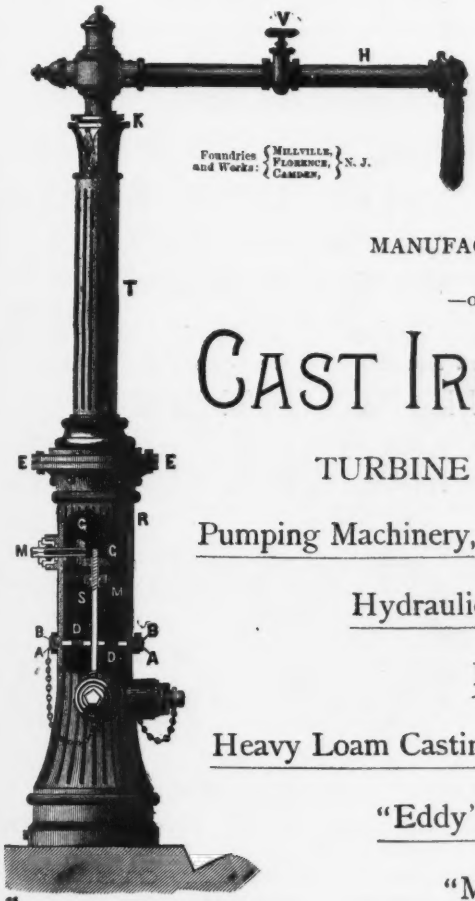

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Pumping Machinery,

Hydraulic Cranes,

Lifts and Machinery,

Heavy Loam Castings,

"Eddy" Valves,

"Mathews'" Hydrants

FIRE HYDRANT
With Crane Attachment for Sprinkling Cart.

s.d.m.j.

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LEAD PIPE, TIN PIPE, SHEET LEAD,
SHEET TIN, RIBBON AND TAPE LEAD,
WHITE LEAD, Dry and in Oil, RED LEAD,
LITHARGE, COPPER AND IRON PUMPS,
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Correspondence with Water Works solicited.

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Has an unparalleled Record of more than Fifty Years.

SALES IN THE UNITED STATES, 7,000,000 BARRELS.

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FROM THE
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ADAPTED FOR
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ALWAYS
RELIABLE.

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UNIFORM IN
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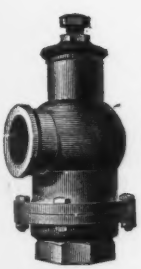

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DEALERS IN

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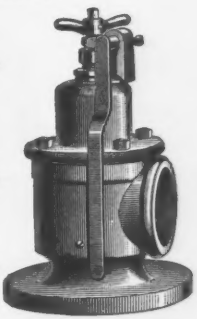

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Office and Works, - BOSTON, MASS.

Branches—New York, Chicago and London, Eng.

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1891.

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LEAD PIPE.

True Centre.

SHEET LEAD.

Extra Width.

WIND TOWER

DROP AND CHILLED SHOT.

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PIG AND INGOT LEAD.

PIG AND BAR TIN. SOLDER.

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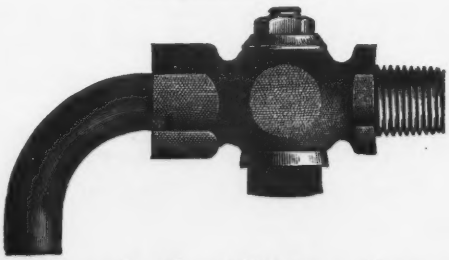
PECK BROS. & CO.,

MANUFACTURERS OF



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A. D. 1891.

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May, - - -	1,252	August, - - -	931
June, - - -	1,138	September, - -	907

Total for Six Months, **6,372.** Average, **1,062** a Month.

WHAT DOES IT MEAN? THESE MONTHLY SALES EXPLAIN IT.

Whole Number Sold, 20,000.

CATALOGUE ON APPLICATION.

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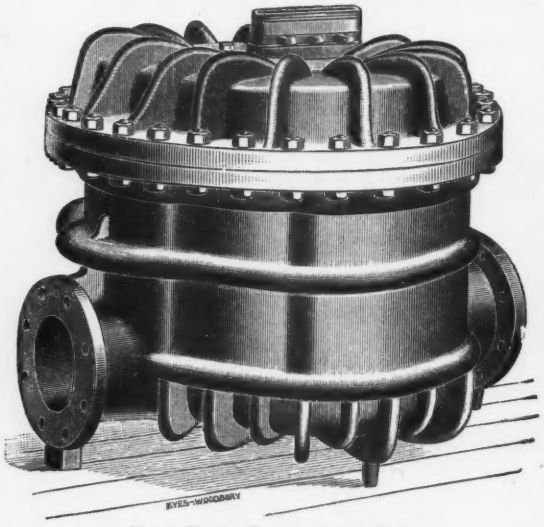
WORCESTER, MASS.

ESTABLISHED IN 1868.

Man'f'rs of the only positive

MEASURING 12-in. METERS.



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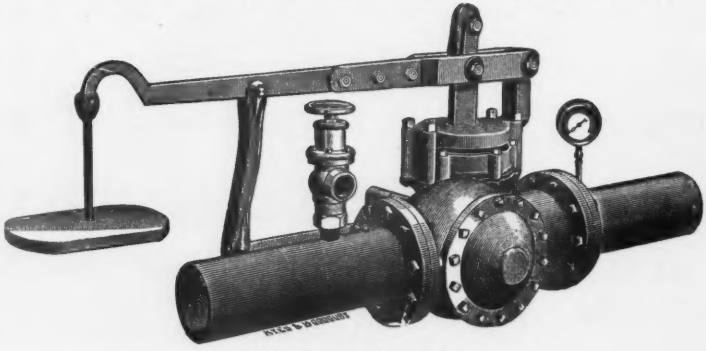

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PIPE,

From 3 to 48 Inches Diameter.

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ALL SIZES OF FLANGED PIPE

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SPECIAL CASTINGS.

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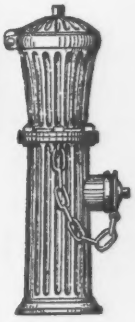

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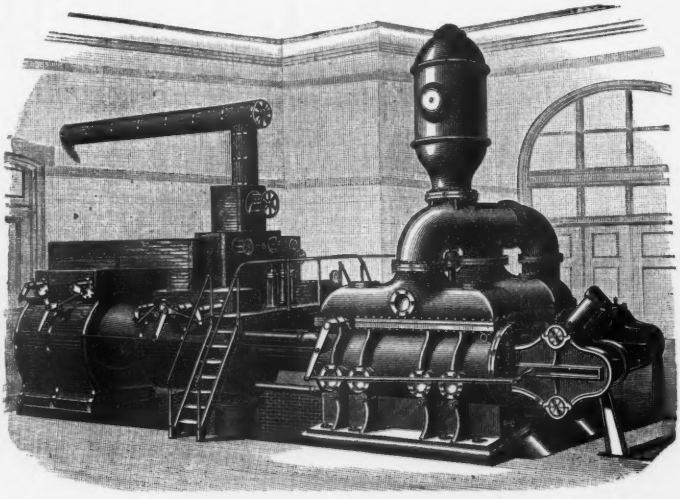

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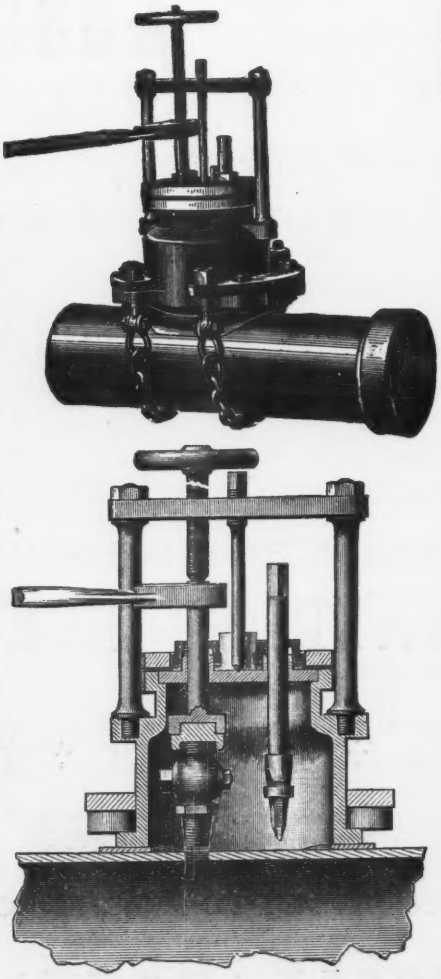

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For tapping main pipes under pressure, ***Simplest and Best. Three Machines in One.*** Body made of Brass, Trimmings of Wrought Iron and Steel.

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HIGH DUTY

PUMPING ENGINES.

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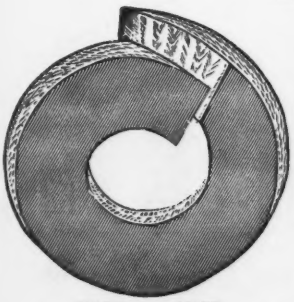

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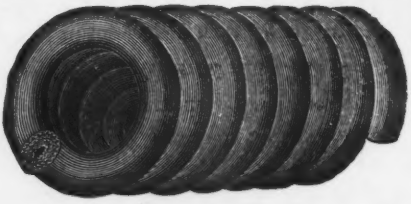

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(With and without Rubber Core),

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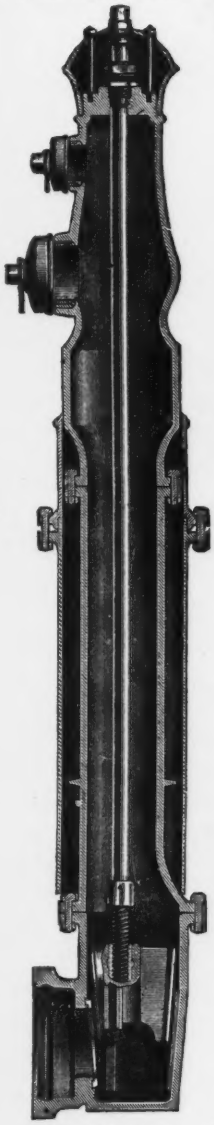
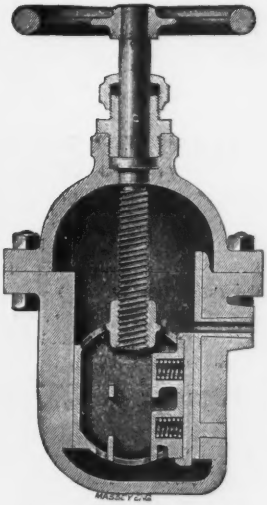


Section Hydrant.

Bell End Water Gate.



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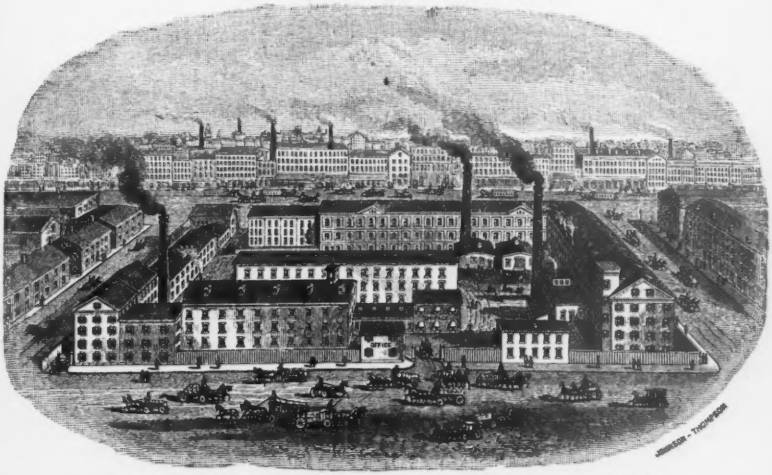

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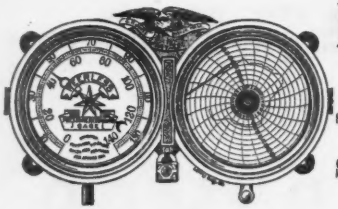

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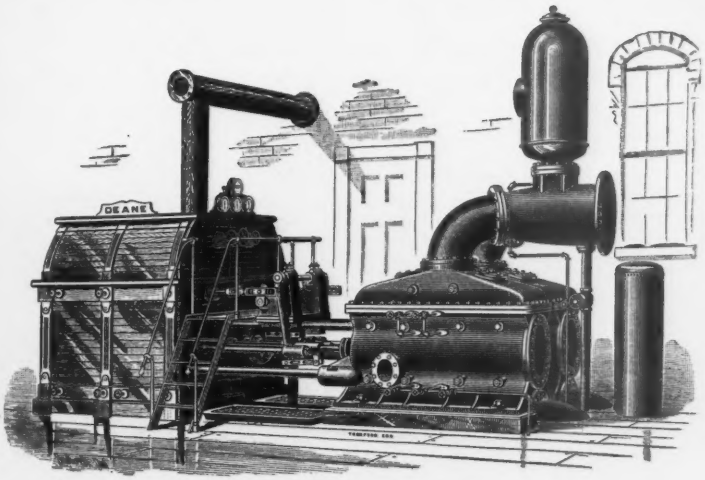

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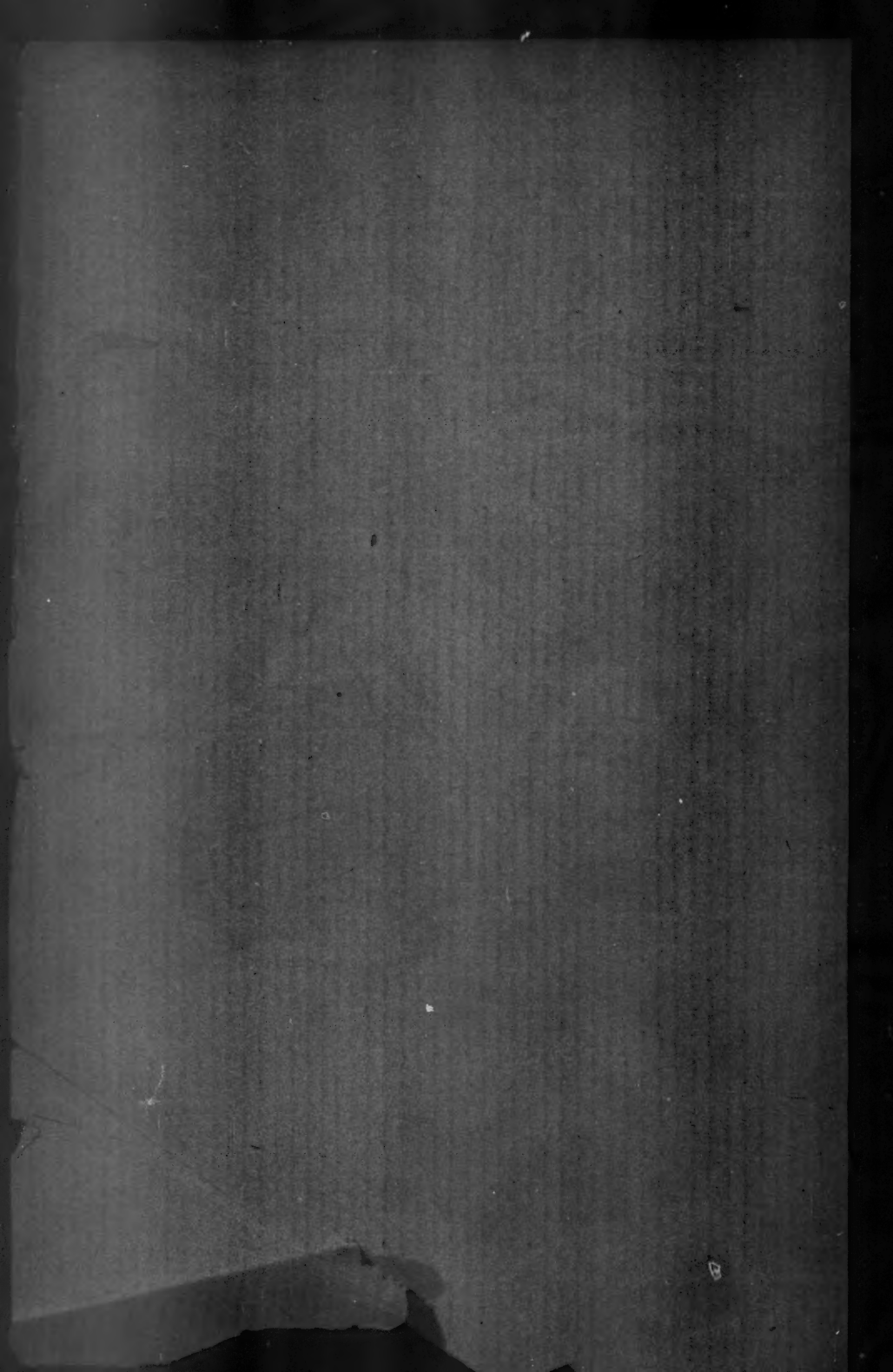
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